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PSYCHOPHYSICAL TESTS OF POTENTIAL DESIGN/CERTIFICATION CRITERIA FOR ADVANCED SUPERSONIC AIRCRAFT

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General Applied Science Laboratories, Incorporated
Westbury, New York

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16. Abstract

A subjective valuation of simulated sonic booms heard indoors and outdoors has been carried out to assess the validity of a simple formulation for estimating perceived noise levels. Using a psychoacoustic experiment design based on magnitude estimation of the perceived level, it was shown that the subjective response was consistent with the predictions of both the simple formula for PLdB as well as PLdB determined from an analysis of the sonic boom stimuli using the MARK VII procedure. Based on thse results it is concluded that perceived sonic boom levels can be adequally predicted by the expression: $PLdB = 55 + 20 \log_{10} \frac{\Delta P}{\tau}$, ΔP in psf, τ in secs.

With regard to acceptability of the sonic boom, it was found that the sonic boom when heard indoors was significantly less acceptable than when heard outdoors for the same level of PLdB. In particular the present data indicate: (a) 90 PLdB(1) when heard inside and measured outside is acceptable to 98% of the subjects tested; a result that is in agreement with the data reported in Federal Aviation Administration Technical Report NO. FAA-RD-73-115. (b) when heard inside and measured inside the PLdB(1) and 98% acceptability is equivalent to 69 PLdB(1) (-21 PLdB attenuation). (c) heard outside and measured outside 90 PLdB(1) is acceptable to 80% of the tested subjects.

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Finally, the authors wish to acknowledge the constructive comments of Dr. James E. Mabry of Man-Acoustics Inc. during this program, and for his independent analysis of the third-octave spectra of the test stimuli, the results of which appear as an appendix to this report.

SECTION I

INTRODUCTION

Both the Federal Aviation Administration and the aerospace industry require design and certification criteria regarding sonic booms to guide them in making appropriate decisions regarding the future of civil supersonic aviation.

Prior research summarized in the sonic boom literature survey[1] provides the basis on which past regulatory and design decisions were based. It appears that the primary criterion used for making sonic boom decisions during the 1964 to 1974 time period was maximum peak overpressure.

What does the future hold for civil supersonic aviation? Are there other possibilities that should be considered to guide decision making regarding sonic boom? That is the purpose of this research. A possibility exists that the overflight sounds of civil supersonic aviation (that is, the perceived levels of their sonic booms) could be certificated in much the same way as aircraft noise. Federal Air Regulations, based on new knowledge, may be amended to prohibit objectionable sonic booms over a set level once acceptable perceived levels are determined.

In order to consider these possibilities, it is necessary to determine what perceived levels of sonic booms would be acceptable under both outdoor and indoor living conditions. It is also necessary to provide the aircraft designer with the key physical sonic boom signature variables which influence the perceived level. Finally, it is necessary to provide the appropriate psychoacoustic measure by which the perceived level of the sonic boom may be expressed most accurately.

The following research is aimed at providing answers to these basic questions and opening the way for future progress and change.

Based on the 1965 work of Zepler and Harel (Reference 2) a memorandum (Reference 3) was written February 21, 1968, and discussed with the Operations and Engineering personnel of the U.S. Supersonic Transport (SST) Development Office urging the adoption of a Sonic Boom Index = $k\Delta P/\tau$. The objective was to communicate with aircraft designers the importance of another sonic boom signature parameter in addition to overpressure, i.e., the interaction of rise-time and overpressure.

It was believed at that time that rise-time τ in the above equation was of equal importance as overpressure, i.e. ΔP in affecting human reaction to sonic booms. This memorandum was followed by papers (References 4, 5, 6) outlining the relationship between overpressure/rise-time and human reaction expressed by Figure 1 and subsequently adding the perceived noise levels based on the Edwards Air Force Base (AFB) Sonic Boom test results. This was possible as a jury of Edwards AFB subjects found sonic booms with an average overpressure of 1.69 psf to be equivalent to the 105 PNdB flyover noise of a KC-135 aircraft (Reference 7).

Convinced that average rise-time was equally important as average overpressure regarding the judged noise level the next step was to determine the rise-time associated with this judgement. A rise-time of 0.005 seconds was found to be appropriate based on available Edwards AFB test data. The noise level for other combinations of $\Delta P/\tau$ could then be calculated based on the conviction that a doubling of overpressure or a halving of rise-time increased the perceived level by 6 PNdB.

It only remained to quantify this relationship as shown subsequently in Equation (1) to arrive at a very quick and simple approach to determining the perceived level of a sonic boom when overpressure and rise-time are known. The most important idea is that the Boom Index and Equation (1) hold the key to unlocking the required design criteria for supersonic aircraft.

The general formula for estimating the perceived levels of a sonic boom was derived as follows:

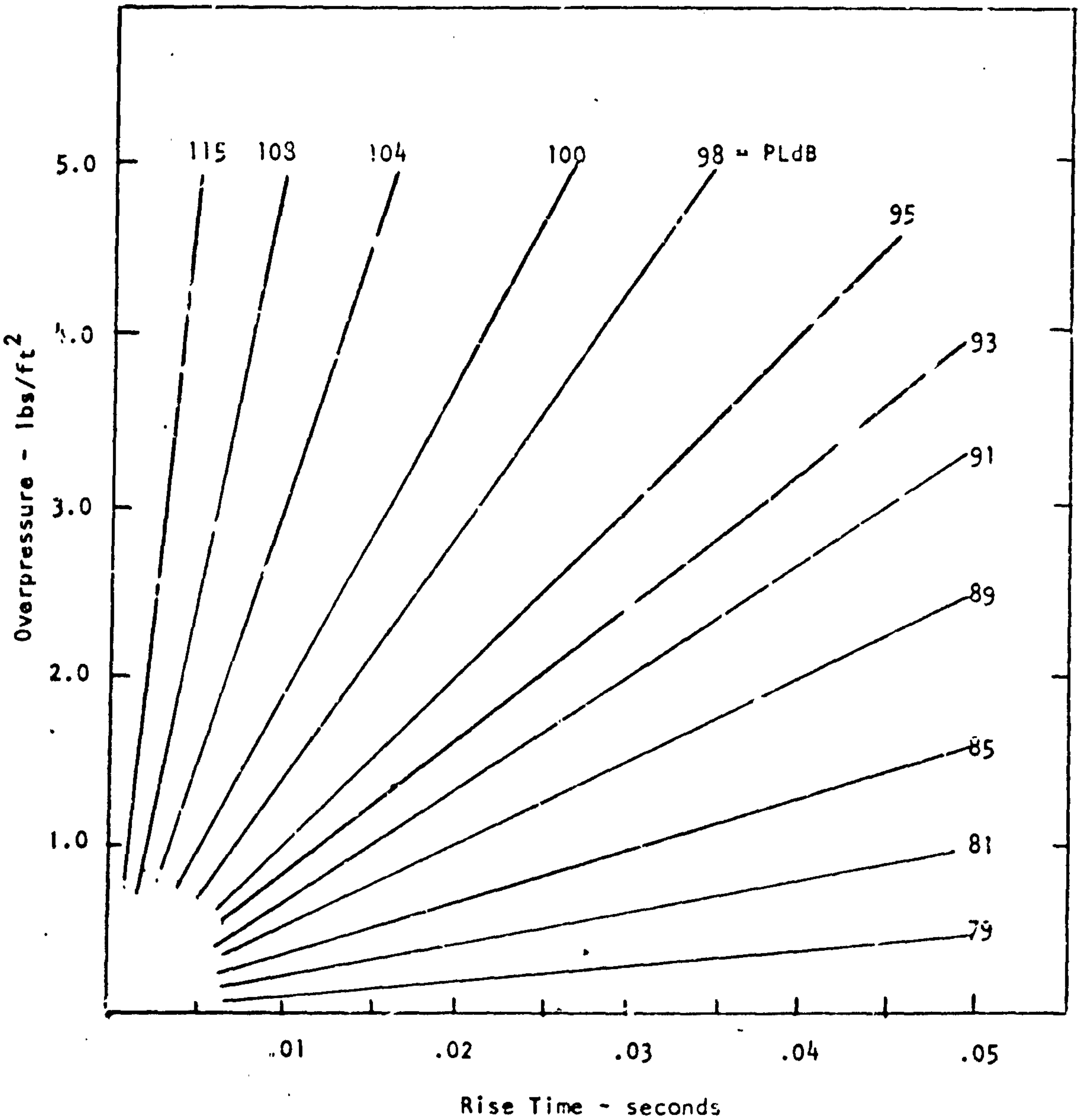


Chart employs the equation: $PLdB = 55 + 20 \log_{10} \frac{\Delta P(psf)}{\tau(SEC)}$

FIGURE 1 - RELATIONSHIP BETWEEN OVERPRESSURE, RISE TIME AND HUMAN REACTION

The Edwards AFB sonic boom test results (Reference 7) indicated that a sonic boom doubled in perceived noise level (PNL) for each 6 PNdB increase as compared to aircraft noise which requires 10 PNdB. Therefore, the PNL of a sonic boom increases as a function of $20 \text{ Log}_{10} X$ as when X doubles or is 2 then the PNL increases by 6 PNdB (20 times .3). The unknown x in the equation is of course the relationship of overpressure per unit time, i.e. $x = \Delta p/\tau$.

The subjects rating the sonic booms at Edwards judged the noise level of a boom averaging 1.69 psf overpressure (ΔP) and rise-time (τ) of 0.005 seconds as being equivalent to aircraft flyover noise of 105 PNdB. Expressing this information mathematically as a linear equation, we have:

$$\text{PNdB} = k + 20 \text{ Log}_{10} \Delta P/\tau$$

$$105 = k + 20 \text{ Log}_{10} 1.69/.005$$

$$105 = k + 20 \text{ Log}_{10} 338$$

$$105 = k + 20 \ (2.5)$$

$$k = 105 - 50$$

$$k = 55$$

The general formula for estimating the perceived level of a sonic boom is, therefore:

$$\text{Perceived Level (PLdB)} = 55 + 20 \text{ Log}_{10} \Delta P \quad (\text{PSF})/\tau \ (\text{SEC}) \qquad (1)$$

Equation (1) is plotted in Figure 1 employing an overpressure versus rise-time plot which yields the appropriate perceived level in decibels, PLdB.

Examination of the psychophysical work completed during the last 30 years (Reference 8) discloses that the annoyance and/or loudness judgements of subjects are very similar in the frequency range of sonic booms generated by high flying supersonic aircraft which are for the most part below 1000 Hz. Therefore, the formula is equally good in measuring and predicting human annoyance or loudness reactions to sonic boom.

For this reason it is proposed that the predictive equation for sonic boom be labeled PLdB, the perceived level in decibels as outlined in the work of S. S. Stevens (Reference 8). The PLdB level may then be construed to be a measure of how people react to sonic booms. The Perceived Level (PLdB) measure has another advantage in that it solves a largely semantic problem. That is, how can one have an acceptable perceived noise level when by definition "noise" is "unwanted sound." As a result, an operating agency has the real problem plus a pseudo problem of trying to find an acceptable level of something that is by definition "unwanted."

To eliminate this problem in communication, it is proposed that the terminology perceived level (PLdB) be adopted by the scientific community. This is borne out by the test findings that there are indeed perceived levels, PLdB, or sonic booms which are acceptable to 100 percent of the people exposed to them.

By studying the above equation, it becomes apparent that a possible design window may be opened if the right overpressure and rise-time conditions for acceptable sonic boom perceived levels are met.

Equation (1) can be easily rewritten to accommodate other units of overpressure measurement. For example:

$$\text{Perceived Level (PLdB)} = 21 + 20 \text{ Log}_{10} \Delta P \; (N/M^2)/\tau \; (SEC) \qquad (2)$$

$$\text{Perceived Level (PLdB)} = 1 + 20 \text{ Log}_{10} \Delta P \; (\mu B)/\tau \; (SEC) \qquad (3)$$

Figure 2 presents a comparison of the results obtained by using Equations (1), (2) or (3) which are identical but use different units of measurement, i.e., psf, N/M^2 and μB respectively with the Fourier transform computer program calculations of Pease (Reference 9) based on the theory of Zepler and Harel (Reference 2).

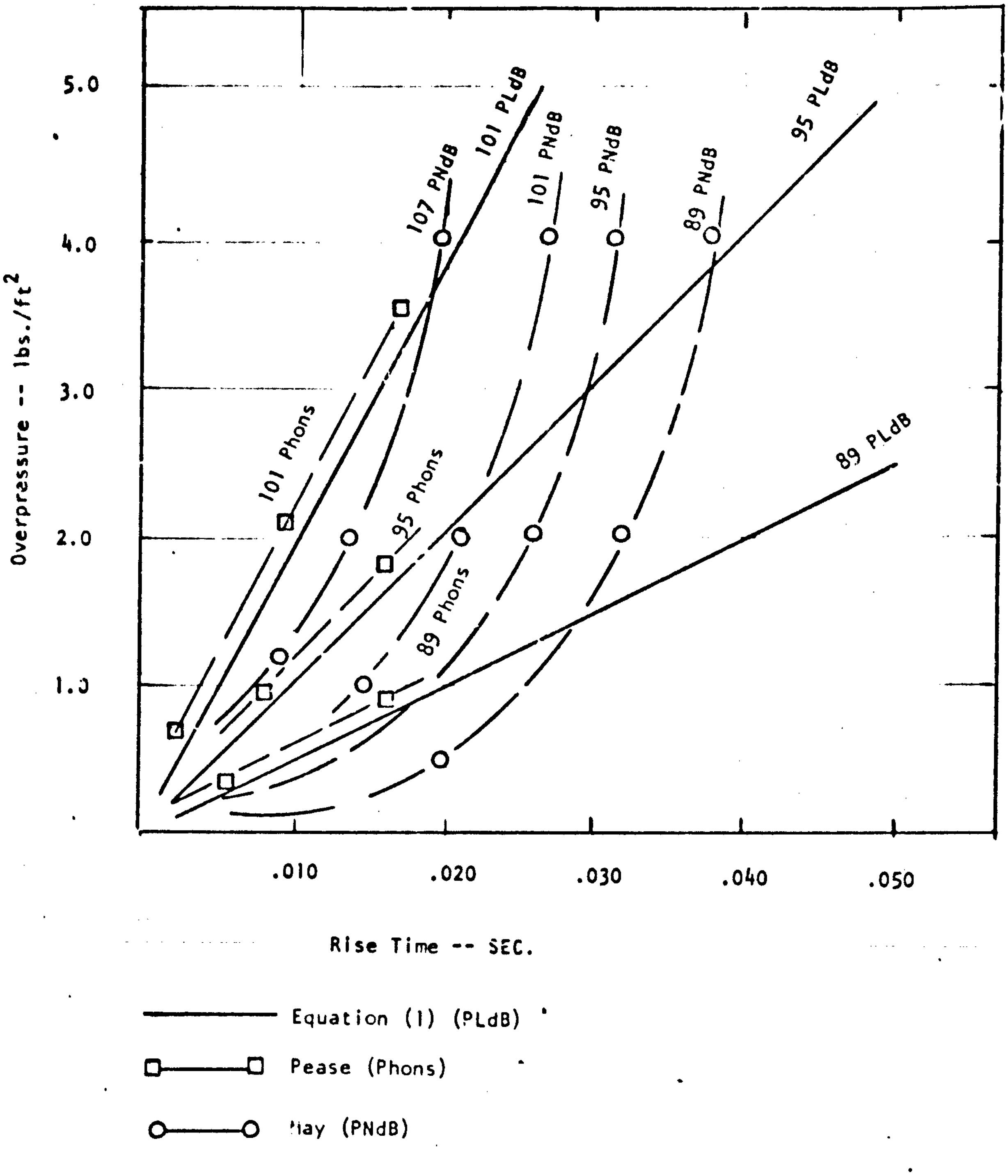


FIGURE 2 - COMPARISON OF PREDICTION BY EQUATION (1) AND METHODS OF PEASE AND MAY

The resulting estimated perceived levels are in good agreement, i.e., within 1 or 2 PLdB of each other in the important potential certification or design window that is in the 90 to 100 PLdB range. These perceived levels are shown subsequently to be acceptable to 95 to 100 percent of the people exposed to them.

Figure 2 also shows that the levels estimated using the method of May (Reference 10) vary considerably with the levels determined by the other two methods.

SECTION II

APPROACH

Human response to noise, as measured through analysis of subjective reactions, can be studied in two ways. A person may respond either in an objectified manner, quantifying his opinion of the noise, or he may be more subjective and respond according to the quality of the noise as it seems to him. In the study being reported, both aspects of subjective response were utilized.

Subjects were invited to listen to simulated booms of various sound levels created through manipulation of over-pressure and rise time parameters. They were told to respond in two ways; first, to rate the annoyance through magnitude estimation; and second, to rate the acceptability with a "yes" or "no" for each boom. In this way, it was expected that we would be able to see how finely people can define a boom's sound level, and also which levels most people would find tolerable. The relationship between these two types of response is very important for those who will design supersonic aircraft, those who will fly them, those who will apply legislation to them, and not least of all, to those who will live under them.

(a) The Test Environment - The sonic boom simulation facility[11] at General Applied Science Laboratories, Inc., was modified for this study in several ways. The aim of the modifications was to create two simulated aspects of home life in which booms might be experienced, outdoors and indoor The outdoor test area was arranged to look like a patio, with bright light,

chairs and table, outdoor carpeting, and a house wall panel on one side, all of which were in the acoustic horn in the direct path of the boom wave. The indoor area was arranged as a 12' x 14' living room with lamp lighting, chairs,couch, and tables, carpeting, simulated windows, and paintings on the wood-panelled walls, all within an acoustic chamber receiving the boom wave at grazing incidence. Taped music was presented in both test areas at an average level of 60 dBA.

Figure (3) shows an overall layout of the test facility and the relationship between the "outdoor", and the "indoor" test areas and the acoustic horn. A more detailed description of the test areas can be gained from Figure (4). As can be seen from the detailed layout of Figure (4)., the two test rooms had one common wall between them. The 8' x 12' separating wall fabricated using standard frame construction techniques, contained a door and a window. The standard size door separating the two test areas was a metal clad door with fiber insulation, typical of the type that might be used for an exterior/interior wall of a residential dwelling. The door was kept closed during test runs, but the double hung, single pane window was left open (approximately 24 inches) to achieve the worst possible indoor condition expected under normal circumstances. (A closed window leads to greater attenuation, and this would only occur in winter or in an air-conditioned house in summer. These situations do not cover the majority of expected conditions for boom occurrence.)

Other significant features of the test setup included a gauze screen located as shown in Figure (4) blocking the tunnel like appearance of the

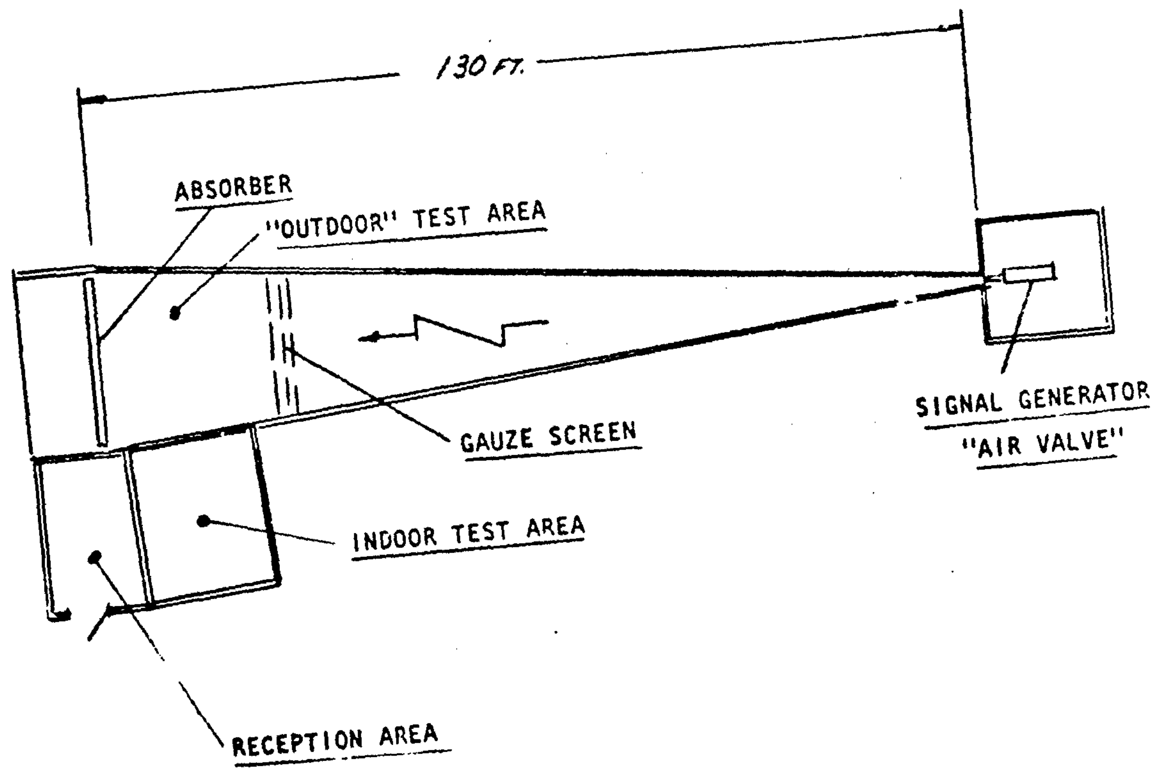


FIGURE 3 - OVERALL LAYOUT OF GASL SONIC BOOM SIMULATOR

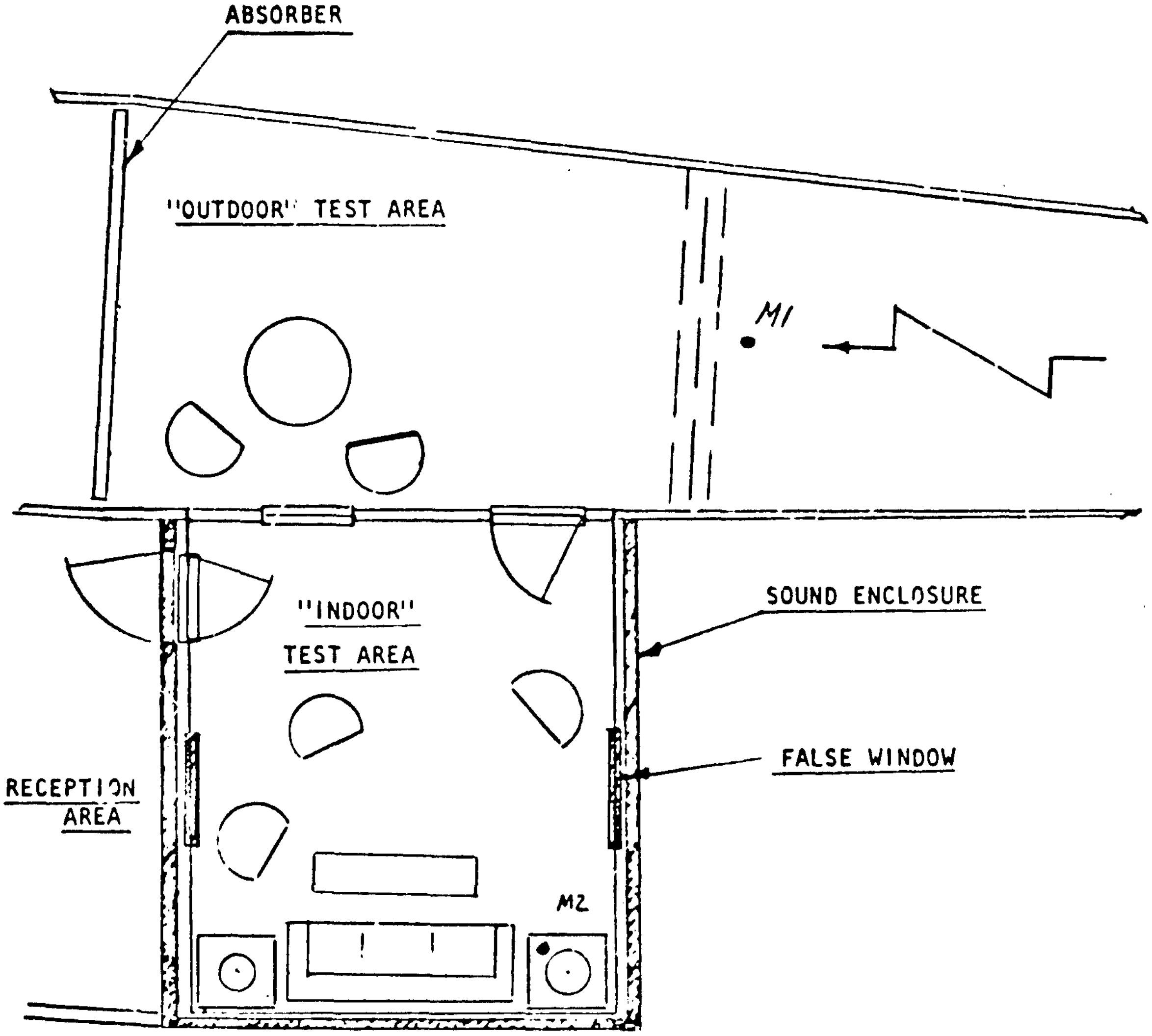


FIGURE 4 - LAYOUT OF THE TEST AREAS

horn from the outdoor subjects. Also of interest is the placement of the monitoring microphones M_1 (the outdoor signal) and M_2 (the indoor signal).

Figure (5) presents a series of photographs showing the appearance of the indoor and outdoor test areas. In Figure (5A) we see the door connecting the reception area with the indoor test area. To the left of the door is one of the false windows (back-lighted to simulate normal outdoor lighting). To the right of the door we observe the open window in the wall separating the indoor and outdoor test areas. A more complete view of the wall can be gained from Figure (5B), which shows the open window and the door in the wall separating the test areas. Finally, Figure (5C), presents a view of the area opposite the wall separating the two test areas. The indoor subjects generally located themselves on the couch or chairs in the area shown in Figure (5C). Figure (5D) is a typical (posed) arrangement showing the seating of two subjects for the indoor tests. Figure (5E), is a view of the "outdoor" test area. On the left can be seen the metal door (interior/exterior), and the open window as installed in the frame construction wall that separated the two test areas. Located behind the posed subject is the chamber which closes the end of the acoustic horn.

From these photographs, it can be seen that indoor subjects were tested in an environment that for all practical purposes was undistinguishable from a normal interior environment. This duplication was not entirely possible for the exterior subjects, since some "unnatural" environmental features, such as the presence of the absorber, and the confining walls of the acoustic

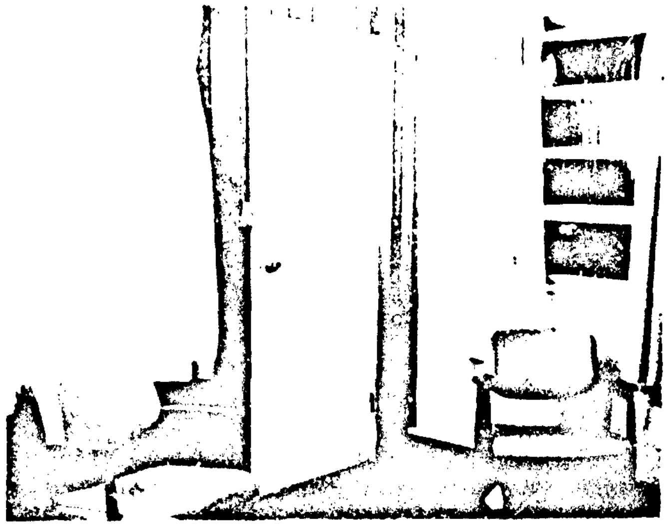


FIGURE 5A - Corner View Showing Entrance Door to Indoor Test Area and Open Window on "Outside" Wall

FIGURE 5B View of "Outside" Wall Showing Open Window and Door Connecting "Indoor" and "Outdoor" test areas.

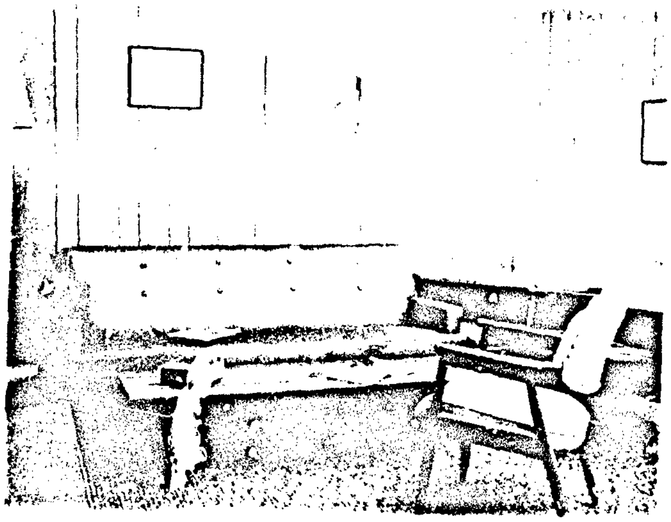
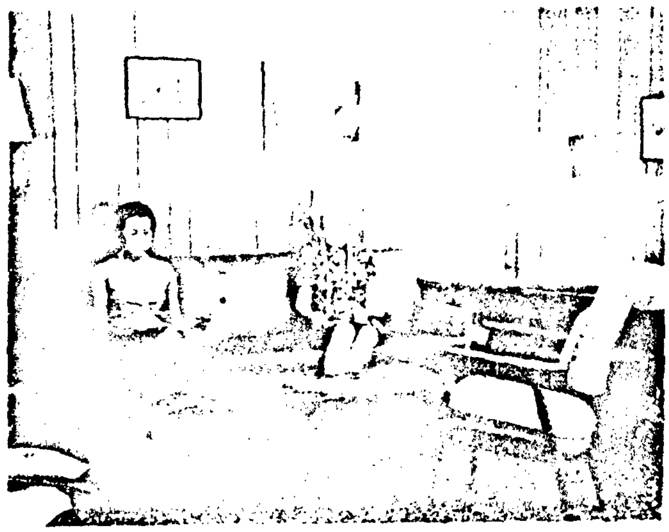
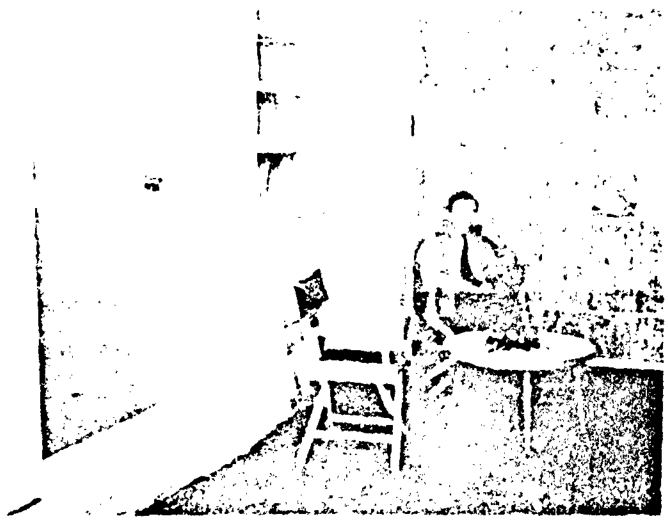


FIGURE 5C - View of Subject Seating Area - Opposite the "Outside" Wall





horn could not be eliminated or entirely masked.

(b) The Test Stimuli - For this program, fifteen different sonic boom signals, designated "boom types", were used as stimuli in the outdoor test area. They are listed in Table I. The phrase "Boom Type" is used to refer to a particular combination of over-pressure and rise time. These combinations were chosen so as to develop a PLdB rating according to Equation (1), as discussed earlier and in Reference 12.

$$\text{PLdB} = 55 + 20 \log_{10} \frac{\Delta P}{\tau} \tag{1}$$

where ΔP is expressed in psf and τ in secs. In the following the notation PLdB (1) will refer to PLdB computed using Equation (1).

Working within the capability of the GASL simulator, five constant levels of outdoor PLdB (1) each separated by 6 dB were generated. Boom Type 7, corresponding to 95 PLdB, and 0.4 psf and 4 msec rise time was chosen as the standard. For all booms the nominal duration was 80-100 msec.

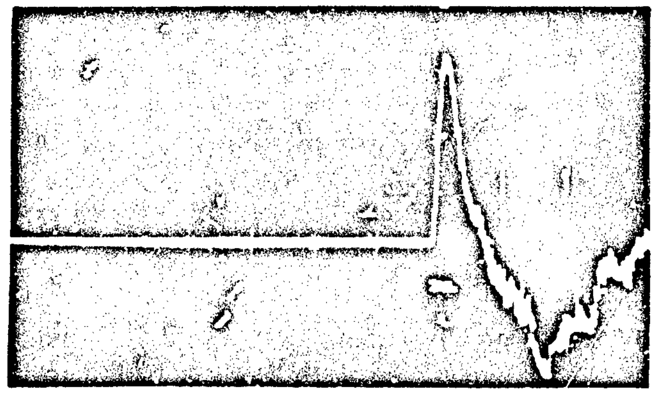
To achieve control of the boom rise time, the air modulation valve used to generate the sonic boom (Reference 11) was modified to permit the rapid interchange of the valve pintle. A separately shaped valve pintle was used for each rise time. Consistent with the firing time required by the test sequence, the valve design was modified so that the pintle could be changed in less than one minute.

TABLE I

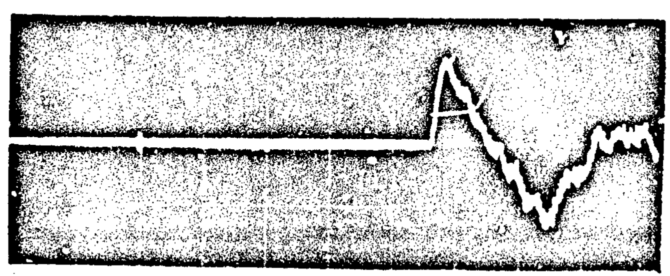
BOOM TYPES

Type	PLdB (1) Level	Outdoor Over-Pressure (ΔP,psf)	Outdoor Rise Time (τ,msec)
1	83	.1	4
2	83	.2	8
3	83	.3	12
4	89	.2	4
5	89	.3	6
6	89	.4	8
7	95	.4	4
8	95	.6	6
9	95	.3	8
10	101	.8	4
11	101	1.2	6
12	101	1.6	8
13	107	1.6	4
14	107	2.4	6
15	107	3.2	8

For All Booms, Duration = 80-100 msec

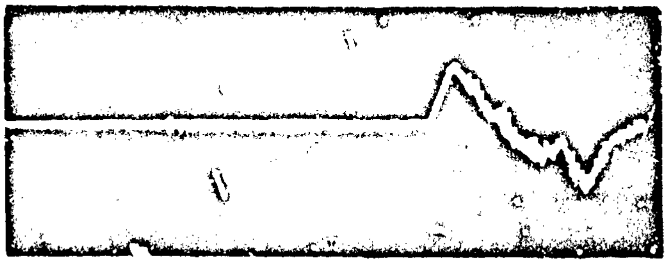


4 msec RISE TIME



6 msec RISE TIME

FIGURE 6A - TYPICAL SONIC BOOMS WITH VARIOUS RISE TIMES



6 m sec RISE TIME

12 m sec RISE TIME

FIGURE 6B - TYPICAL SONIC BOOM (Cont'd)

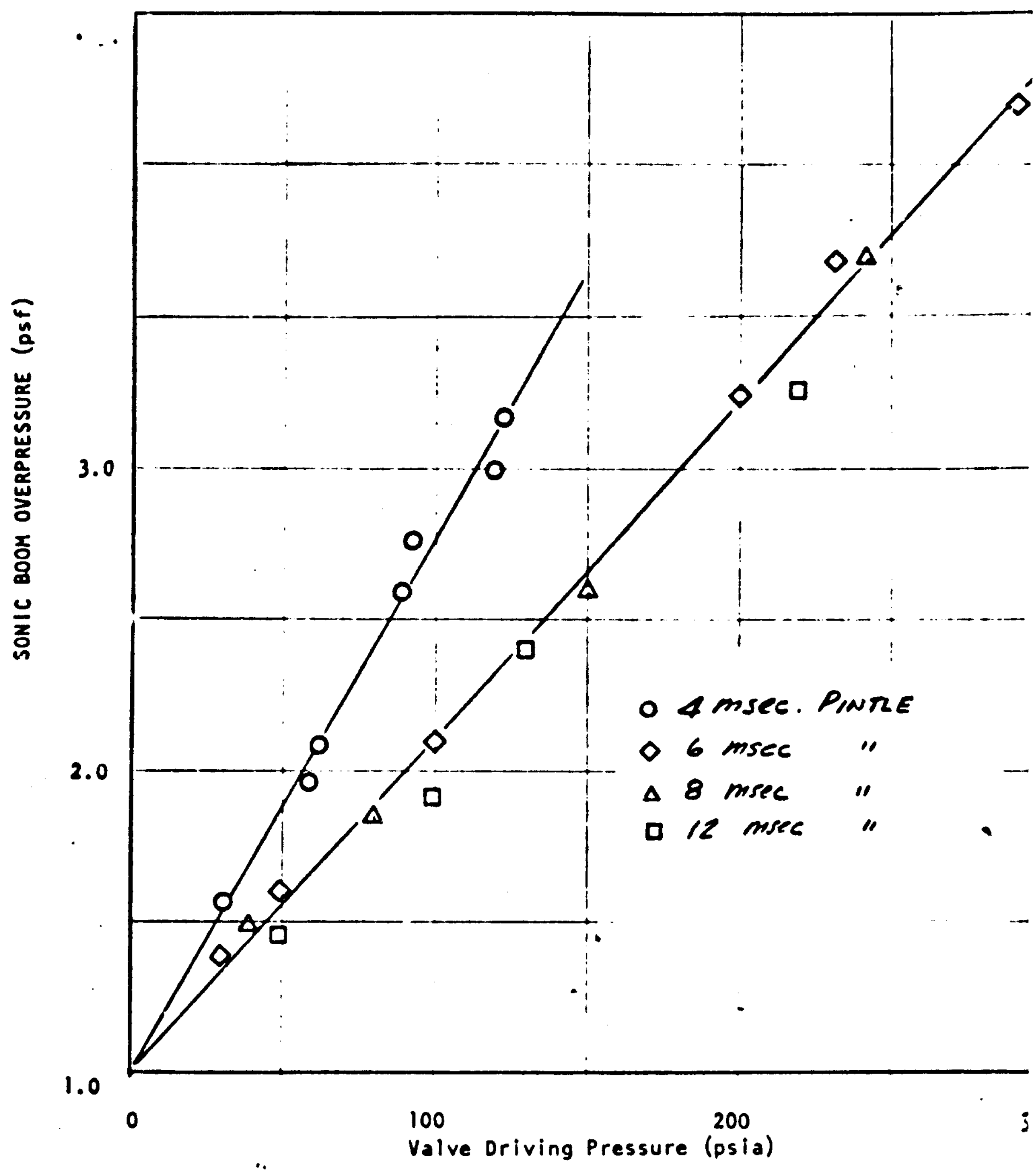


FIGURE 7 - SONIC BOOM VALVE CALIBRATION DATA

OUTDOOR

INDOOR

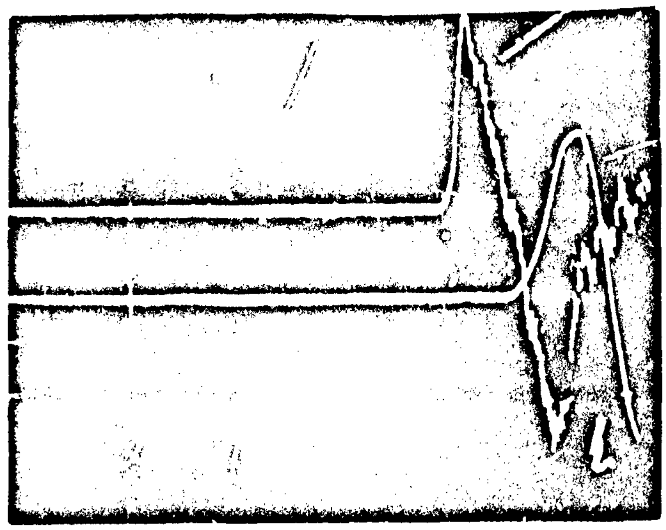


FIGURE 8 - INDOOR AND OUTDOOR SONIC BOOMS

Figure (6) shows the typical sonic boom signals for each of the rise times used during the testing program. Each of the pintles used to generate a given rise time signal was separately calibrated. Figure (7) illustrates the calibration data for each of the four pintles designed for these experiments.

The results of the calibration show that the generated signals are in the linear regime i.e., all the signals are proportional to the system driving pressure level.

Shown in Figure (8) is a typical indoor test signal. The attenuation of the outdoor test signal on being transmitted through the test wall, with the window open and the door closed, resulted in an indoor test stimuli with the following characteristics:

1) A nearly constant rise time of 22 msec. regardless of the exterior signal rise time.

2) An interior peak over-pressure that was attenuated by a factor of 0.37 times the exterior over-pressure.

For each of the outdoor sonic booms, there is, therefore, a corresponding sonic boom of lower PLdB (1) level heard indoors.

To obtain an independent assessment of the loudness level of the sonic boom stimuli used in these experiments, a third octave band spectrum was determined

for several representative signals generated by the simulator and analyzed according to the MARK VII calculation procedure for PLdB (Reference 8).

Measurements and the determination of the third octave spectra were made by the consulting firm of Donely, Miller and Nowikas. Instrumentation used consisted of

1. Microphone Calibrator: B&K 4220 Pistonphone,
   Serial No. 321641

2. Microphone: 1" B&K 4132 Pressure Response

3. Cable: 30M B&K

4. Signal Conditioner: B&K 2204/S Precision Sound Level Meter
   Serial No. 313739

5. Analyzer: B&K 1/3 Octave-Band Real-Time Analyzer

6. Graphic Level Recorder: B&K 2305

For purpose of illustration the spectra corresponding to a typical 4 msec and an 8 msec simulated boom are shown in Figures (9) and (10) respectively, and superimposed to show the difference in Figure (11). These particular spectra shown both correspond to a peak value of an over-pressure of 1.13 psf. By

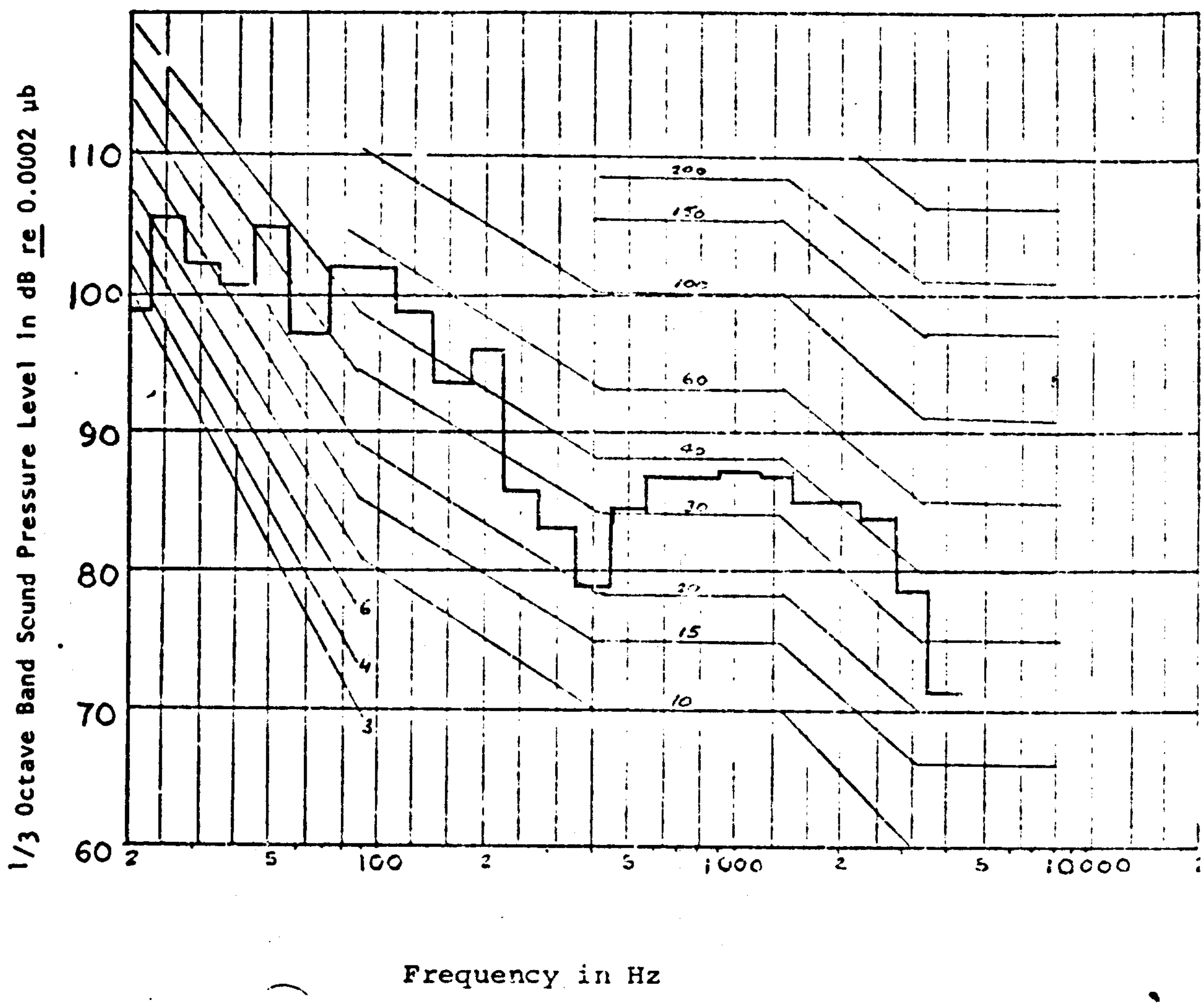


FIGURE 9 - THIRD OCTAVE-BAND SPECTRUM FOR SIMULATED OUTDOOR SONIC BOOM, ΔP = 1.13 psf and τ = .004 secs

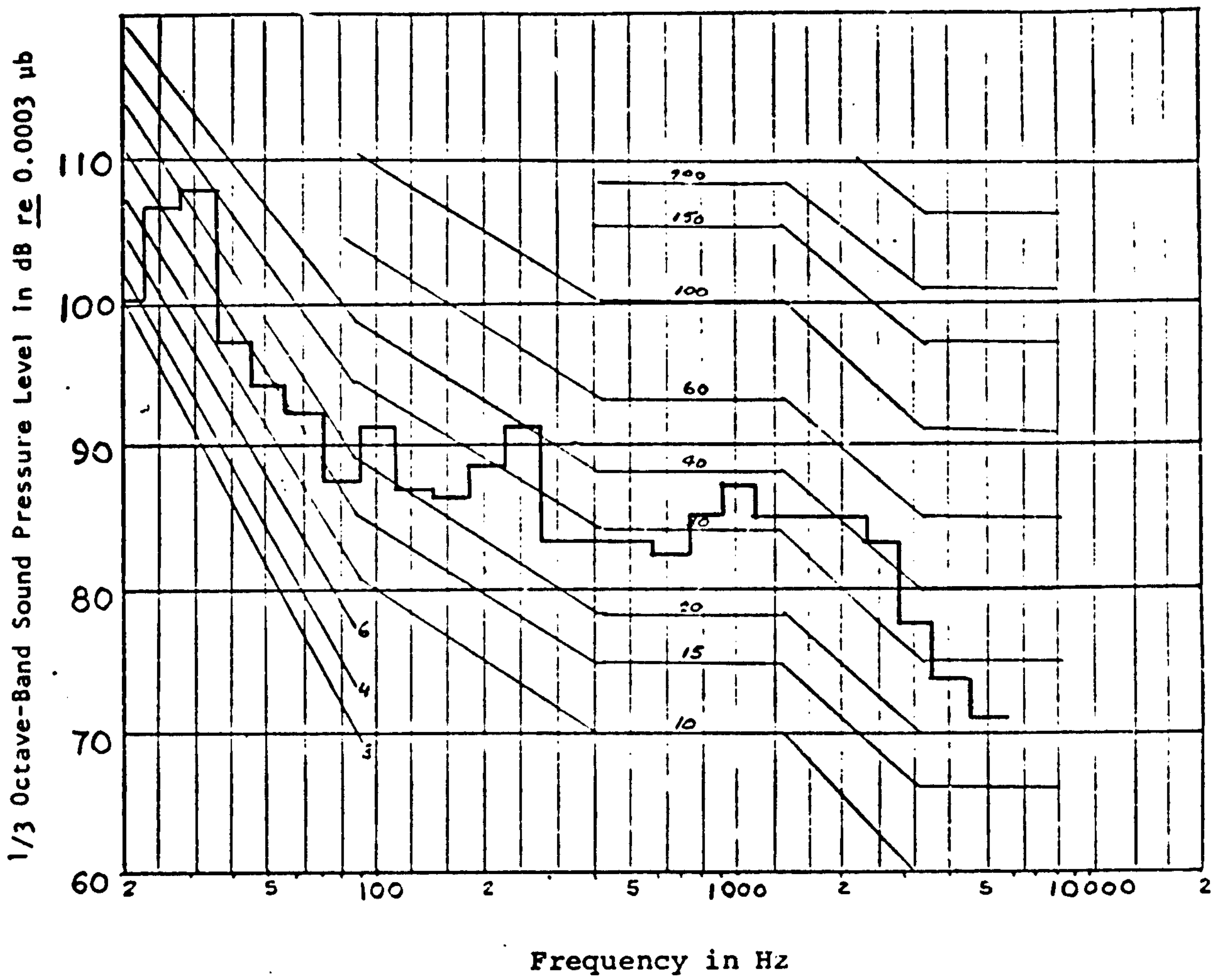


FIGURE 10 - THIRD OCTAVE-BAND SPECTRUM FOR SIMULATED OUTDOOR SONIC BOOM, ΔP = 1.13 psf and τ = .008 secs

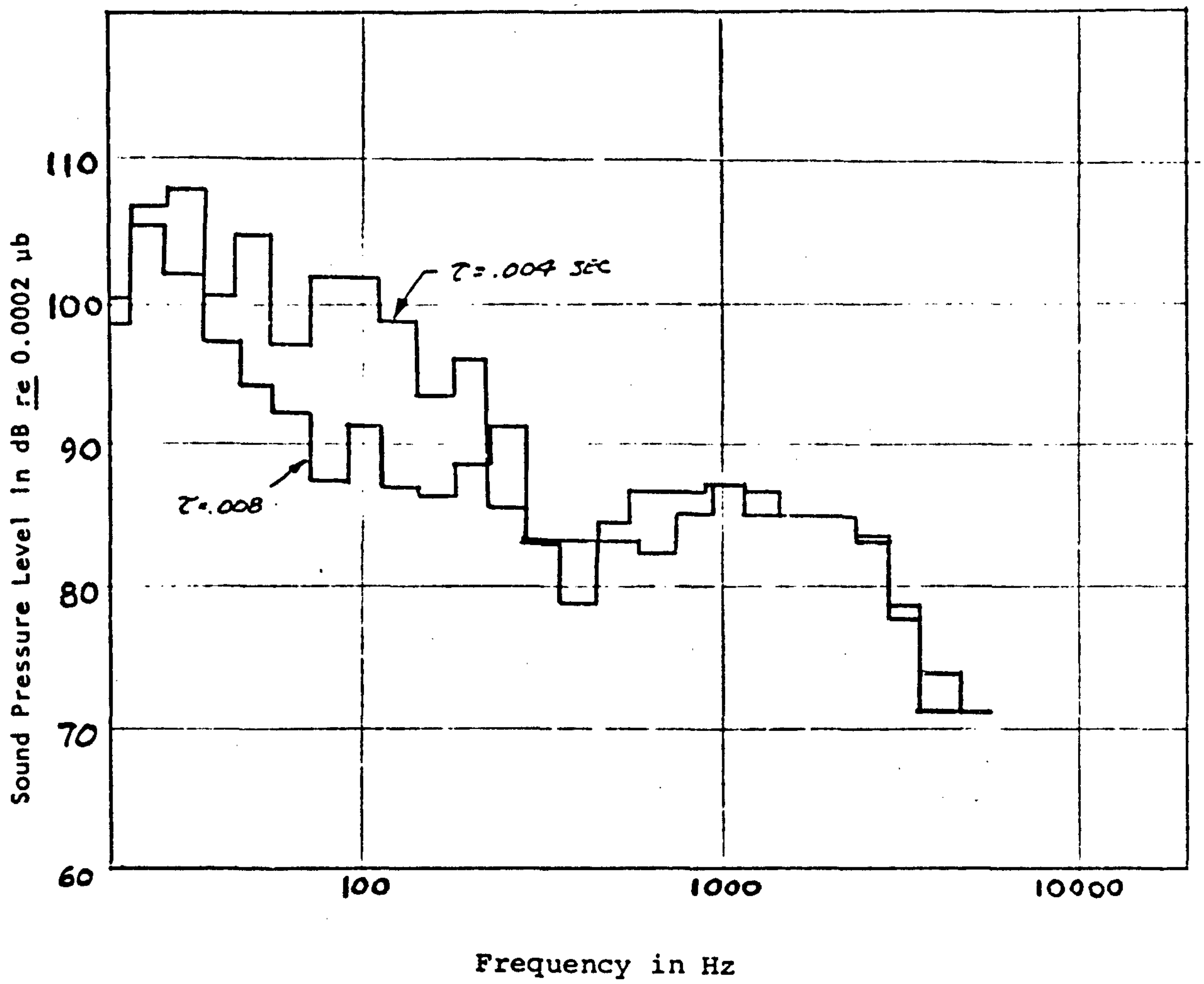


FIGURE 11 - SUPERPOSITION OF 4 and 8 msec SPECTRA
OF FIGURES 9 and 10

comparing the two spectra we observe a significant reduction in the sound pressure level in the neighborhood of 100 Hz: the 8 msec data being lower than the 4 msec data in this frequency range as expected. At the very low and at the higher frequencies, the spectra are very nearly alike.

Analysis of these two particular signals by the MARK VII procedure, and comparison with the prediction from Equation(1) shows agreement within 1.5 dB for the 8 msec signal, and 2.5 dB for the 4 msec signal as indicated in the following table.

	PLdB	
	Eq. (1)	MARK VII
ΔP = 1.13 psf τ = 4 msec	104	101.5
ΔP = 1.13 psf τ = 8 msec	98	97.5

A comparison of the test stimuli, both indoor and outdoor, as determined by Equation (1) (PLdB (1), and from the third octave spectra accord' ͜ to the MARK VII procedure is given in Tables II and III.

In the case of the outdoor signals the PLdB level predicted by MARK VII

TABLE II

ANALYSIS OF THE OUTDOOR STIMULI

Boom Type	PLdB (1)	PLdB (MARK VII)
1	83	78
2	83	85.7
3	83	-
4	89	85
5	89	84.6
6	89	91
7	95	91.5
8	95	91.5
9	95	97
10	101	99.5
11	101	97.5
12	101	102.5
13	107	104.5
14	107	103.5
15	107	109.5

TABLE III

ANALYSIS OF THE INDOOR STIMULI

Boom Type	PLdB (1)	PLdB (MARK VII)
1	59.5	53
2	65.5	57.8
3	69	-
4	65.5	58.8
5	69	65.5
6	71.5	64.6
7	71.5	65.6
8	75	70.8
9	77.5	70.8
10	77.5	71.6
11	81	76
12	83.5	76.3
13	83.5	78
14	87	81.5
15	89.5	82.5

yields results both lower and higher than that hypothesized by Equation (1) Except for the lowest level signal the observed variation spans the range between + 2.5 dB and - 3.5 dB.

In the case of the indoor signals the comparison between the prediction by Equation (1) and MARK VII is not as good, with MARK VII PLdB levels always lower than the PLdB (1) levels. The observed variation between the two predictions being in the range of - 3.5 dB to as much as -7.7 dB. The indoor PLdB (1) levels were based on the measured indoor over-pressure and rise times.

(c) The Subjects - The subjects for this study were chosen from a pool of 220 people, most of whom lived in middle-income suburban housing not far from the test facility, and a few others who were affiliated with General Applied Science Laboratories, Inc. The nearby residents had been interviewed several months earlier in a Columbia University study of aircraft noise pollution. From this pool, 42 subjects were selected at random. Of the 42, 11 were male. The age range for the subjects was 23 to 65, averaging in the middle 40's. All subjects used reported their hearing as good. Also, 17 subjects reported having heard sonic booms at one time or another.

The subjects for the test were screened for noise sensitivity on a standardized scale of 0 to 10, 0 to 4 being low, 5 to 10 being high. The noise sensitivity question used for the screening was taken from the study of "Booms in the Oklahoma City Area", Nat. Op. Res. Ctr. 101, AMRL TR -65-37 and consisted of the following instructions to the test subjects:

NOISE SENSITIVITY QUESTION

Now here's a different kind of question, I have a list of noises which sometimes annoy people. Do these ever annoy you when you hear them? (Read List)

First:

		Annoy Yes	Annoy No	Never Hear
A.	The noise of a lawn mower	1	1	1
B.	A dripping faucet	2	2	2
C.	A dog barking continuously	3	3	3
D.	The sound of a knife scraping on a plate	4	4	4
E.	Somebody whistling out of tune	5	5	5
F.	Chalk scraping a blackboard	6	6	6
G.	A pneumatic drill or air hammer	7	7	7
H.	A banging door	8	8	8
I.	Muciscal instruments in practice	9	9	9
J.	Typewriters	0	0	0

Based upon this screening the following results were found. Of the whole pool, 42.3% were of low sensitivity, while 42.9% of the test subjects were of high sensitivity. The median score of both groups was 5, pool $\sigma = 2.2$, subject $\sigma = 2.3$. Results of the screening are given in Figure (12).

In addition, subjects were asked about their attitudes toward commercial supersonic aircraft. These questions sought to determine each subject's feelings on the necessity and desirability of the SST for a possible correlation with annoyance ratings. The results of this part of the study will be presented later in this report.

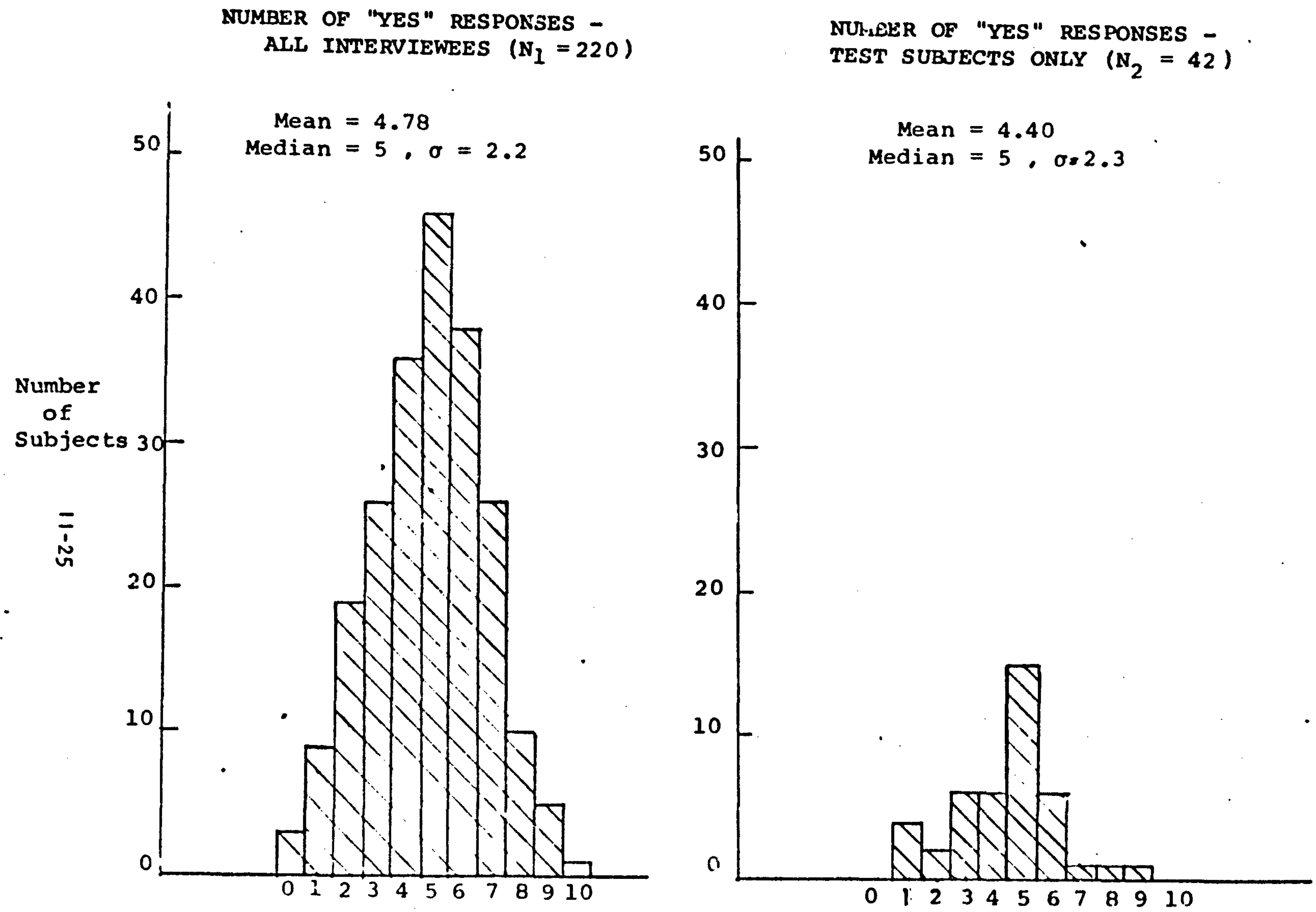


FIGURE 12 - GENERAL NOISE SENSITIVITIES

The SST attitude question was also taken from report "Booms in the Oklahoma City Area", AMRL TR-65-37, and consisted of the following inquiry:

SST ATTITUDE QUESTION

As you may know there has been a government development program of a new supersonic airplane that will fly about 2000 miles an hour. Do you feel it is absolutely necessary for our country to have such a civilian plane, do you feel it is probably necessary, or do you feel it is not necessary?

Absolutely Necessary	1
Probably Necessary	2*
Not Necessary	3*
Don't Know	4*

*IF PROBABLY, NOT, OR DON'T KNOW, ASK A.

A. As you may know, the French, British and the Russians are already building a commercial supersonic airplane. If these countries have such a plane, would you feel it absolutely necessary for Americans to make one too, would it probably be necessary, or would it not be necessary?

Absolutely Necessary	1
Probably Necessary	2**
Not Necessary	3**
Don't Know	4**

**IF PROBABLY, NOT, OR DON'T KNOW ON "A", ASK B

B. If the sonic boom could be reduced, would you feel it desirable for us to have a commercial plane that travels about 2000 miles an hour, or don't you feel we need such a plane?

Desirable	1
Not Necessary	2
Don't Know	3

(d) Procedure - During each test session there were a total of 4 subjects being tested, 2 in the outdoor condition and 2 in the indoor condition. The test stimuli were sonic booms at 5 different PLdB (1) levels, each level containing 3 booms with different combinations of over-pressure and rise time. This total of 15 boom types was presented twice, in different random orders of presentation to minimize order effects, for a total of 30 booms to be rated by each subject in two test runs. A typical session plan follows.

The 4 paid subjects are taken into the "living room". After confirming their volunteer status, the subjects are instructed about the test requirements and the use of magnitude estimation.* Then the two subjects chosen randomly for the "patio" are taken out to their seats, and three booms are presented with the subjects in their test positions. The first is 6 PLdB (1) louder than the standard, the second 6 PLdB (1) below the standard. No information is given to the subjects about these booms. Finally, the third boom at 95 PLdB (1) is presented as the standard. The subjects are told to assign an annoyance score of 10 to it and judge all other booms in relation to it. Acceptability is an independent factor. The standard is repeated just prior to the first series of 15, and then the 15 booms come at approximately 2½ minute intervals, unannounced. They are asked via intercom to respond after each boom.

After a short coffee break, the standard is repeated and the same 15 booms in a different order follow as before. The test takes nearly two hours from the subjects arrival to departure.

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*The instructions to the subjects, and a sample rating sheet used during this program follow.

The subjects occupied themselves with conversation, card games, reading, or writing. Several enjoyed the music, as evidenced in comments or singing and whistling.

If a session had only 3 subjects, a substitute, non-responding fourth was added. This action had to b taken on two occasions.

The following is the set of instructions given the subjects.

INSTRUCTIONS

Please go into the (living room/patio) and take a seat. As you know, this is part of an environmental research program dealing with the reactions of people to the sonic boom.

Here are some magazines, newspapers and games which you may use, and we will play some soft music through this speaker. From time to time you will hear, unannounced, a sonic boom: some may seem louder, others quieter. After each boom, you will record your judgements of it.

As a routine requirement, I would like you to fill out this simple consent form which indicates that you are volunteering to assist us in this research program. This is the paper I mentioned on the telephone.

This is your reaction sheet. Please fill in the top three lines. Condition means indoor or outdoor. In the left-hand column, under "Annoyance", I would like you to record the extent to which each boom bothered or annoyed you. You will do this when I ask you via the intercom to respond. In a moment, we will have you listen to a boom which has an annoyance level we consider 10 units. Use that boom as a standard, and judge each succeeding boom in relation to that standard. For example, if a boom seems <u>twice</u> as annoying as the standard, you will write 20 in the space for that boom on the answer sheet. If it seems only one-quarter as annoying, write 2.5. If it seems <u>three</u> times as annoying, write 30. If <u>one-half</u> as annoying, write 5, and so on. You can write any number, as long as your rating is in relation to the standard of 10. There's no right or wrong answer - we just want to know how you feel. Any questions?

After recording your annoyance response, I want you to place a check under "yes" or "no" in the right-hand column under "Acceptable" to indicate whether or not you believe the boom you have just heard would be acceptable to you. By this I mean whether or not you feel that you could learn to live with it, if you heard it regularly in your own home.

Please notice there are 15 lines. There will be a total of 15 times in each of 2 sessions when you will record your responses. Each time you are asked to respond, you will enter 2 answers: a number to indicate your feelings of annoyance in relation to the standard, and a check under "yes" or "no" to show whether or not you could learn to live with this annoyance. Are there any questions?

To familiarize you with sonic booms before we go on, we will now hear 3 of them. The first will be loud, and the second will be much quieter. Then we will hear the standard, which we have assigned a value of 10. You'll hear it again just before we start our program. You don't have to respond to these; just listen.

There will be 2 sessions, each about 40 minutes long. Between sessions we'll have a short coffee break. During the sessions, we would like you to remain seated as you are now until I return. Also, if you have to talk to one of us, for example, if the music stops suddenly or a light goes out, you can do so by depressing the white button on the intercom and holding it down while you speak. Please tell us your location so we'll know where the problem is. This is the (living room/patio).

One more important request. Your ratings should reflect only your own opinion of the booms, so please record your own personal feelings. Try not to influence each other by avoiding any discussion or other indication of how you yourself feel. Of course, you may talk about anything else as you would in your home. Any questions?

I'll be back in about 40 minutes. We will have the standard boom, with its annoyance score of 10, once more after I leave. Just listen to it; you won't rate it. Then we will begin the series of booms which you will rate for annoyance and acceptability when you are asked.

DATE: ______________________________

CONDITION: ______________________________

If the noise you are rating is two times as annoying as the Standard, write "20" in the space for that noise. If it is one-half as annoying, write "5" and so on.

	ANNOYANCE	ACCEPTABLE	
Noise Number	Rating	(Check one) Yes	No
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

SAMPLE REACTION SHEET USED BY TEST PARTICIPANTS

SECTION III
RESULTS

(a) Annoyance Scores - By and large the subjects had little difficulty in the use of magnitude estimation. The only difficulty reported by a few subjects was the feeling they couldn't recall the standard towards the end of the series of 15 booms. However, a check of the average rating for the standard boom by each person shows that, despite their lack of conscious recall, they were all doing fairly well in rating the standard at about 10 when it occurred in the series of 15. It will be recalled that each series of the test session was a random order of booms, and different series were used in each test session. The average response to the standard boom outdoors was 11.54, with a standard deviation, $\sigma = 4.3$; while indoors it was 12.55, $\sigma = 6.2$. Because each group heard the standard in the same environment as the series for ratings, we can combine the groups and get an overall mean rating of 12.04, $\sigma = 5.3$.

Figure (13) presents the average magnitude estimation scores reported by the 21 subjects who listened to the outdoor boom. For each boom, the corresponding PLdB(1) level is indicated. Each point is labelled according to the outdoor boom type number.

In order to relate the magnitude estimation score to a PLdB level, the average magnitude estimation score was converted to an equivalent PLdB level by assigning a PLdB(1) value of 95 to the Magnitude Estimation value of 10. Other

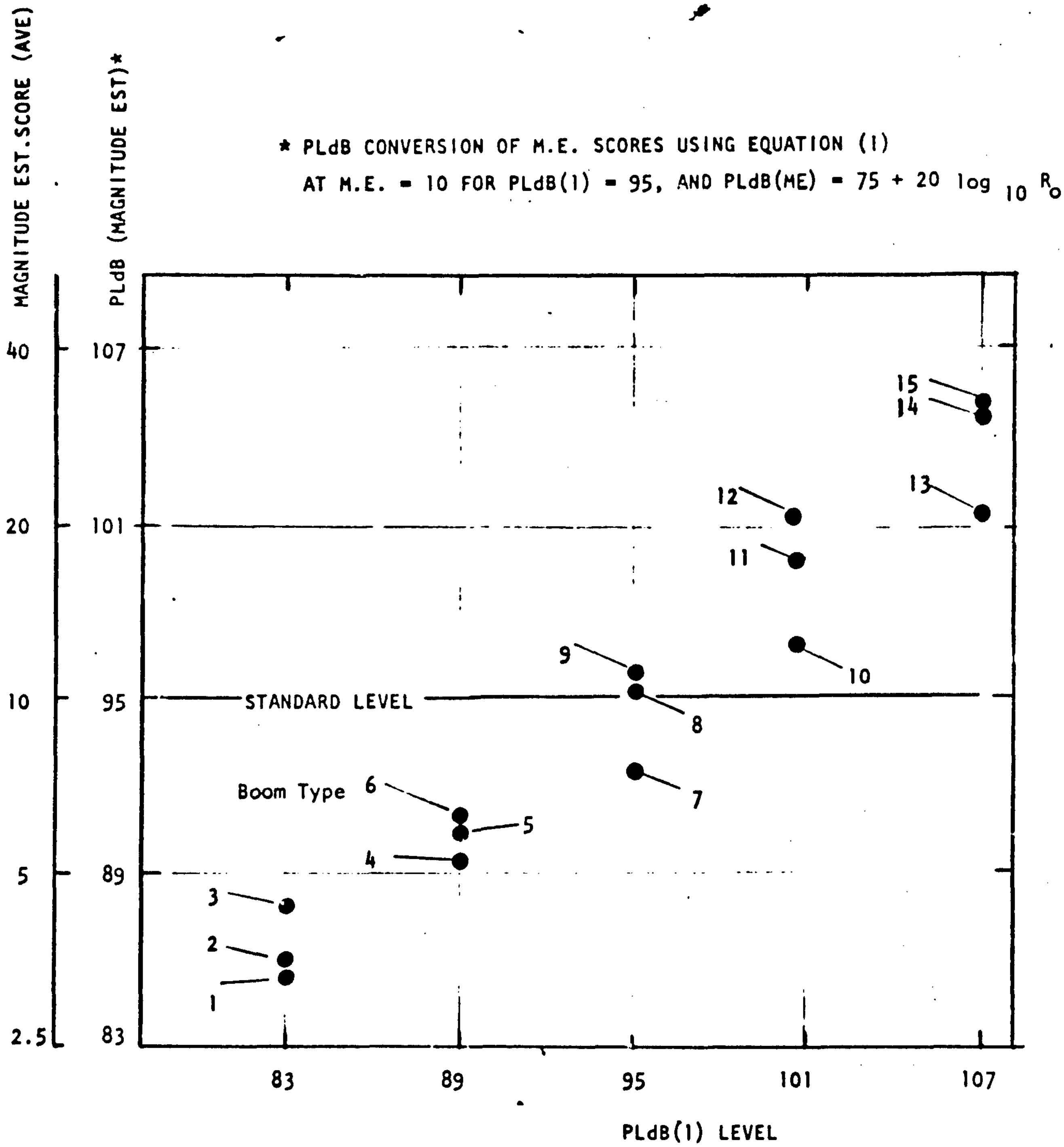


FIGURE 13 - DIVERSITY WITHIN THEORETICALLY-SIMILAR PLdB LEVELS RESULTING FROM MANIPULATION OF τ and ΔP OUTDOOR RESULTS - 21 SUBJECTS

values of magnitude estimation are then adjusted by a 6dB scaling for doubling or halving from the standard level of M.E. = 10 (PLdB(1) = 95) according to the relation

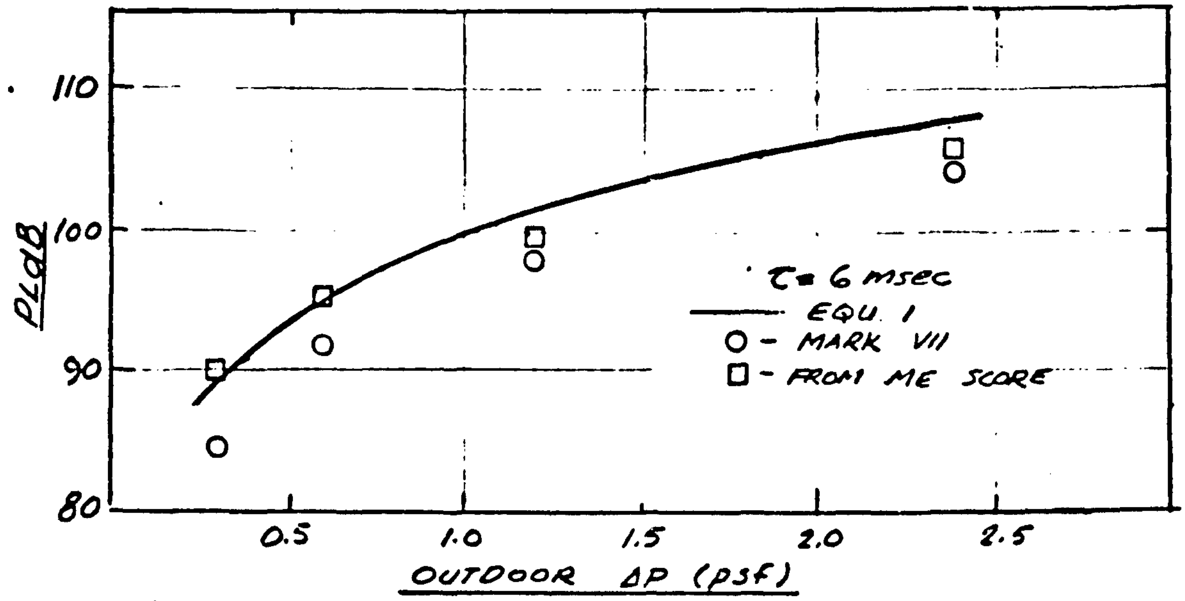
$$PLdB(M.E.) = 75 + 20 \log_{10} R$$

where R_o is the outdoor magnitude estimation response.

Conversion of the M.E. scores in this manner permits a direct comparison of the subjective results with Equation (1), and the MARK VII results. Such a comparison is given in Table IV which compares the average magnitude estimation outdoor scores with the levels predicted by Equation (1), and MARK VII procedure.

The same information is presented in graphical form in Figure (14) where the PLdB results are plotted as a function of outdoor over-pressure for a constant value of rise time.

The results show that quite reasonable agreement exists between the engineering prediction method and the prediction obtained by the MARK VII analysis of the test signals. This agreement serves to substantiate the adequacy of the engineering relation vis-a-vis the more complex MARK VII procedure. In addition, the agreement between the subjective magnitide estimation scores converted to PLdB and the prediction of PLdB by the two methods suggests that the psycho acoustic experiment design and test procedure resulted in a valid measure of subjective response. Based on these results we conclude that the engineering method discussed can be used to predict PLdB levels in the range of sonic boom parameters covered by the present experiments.



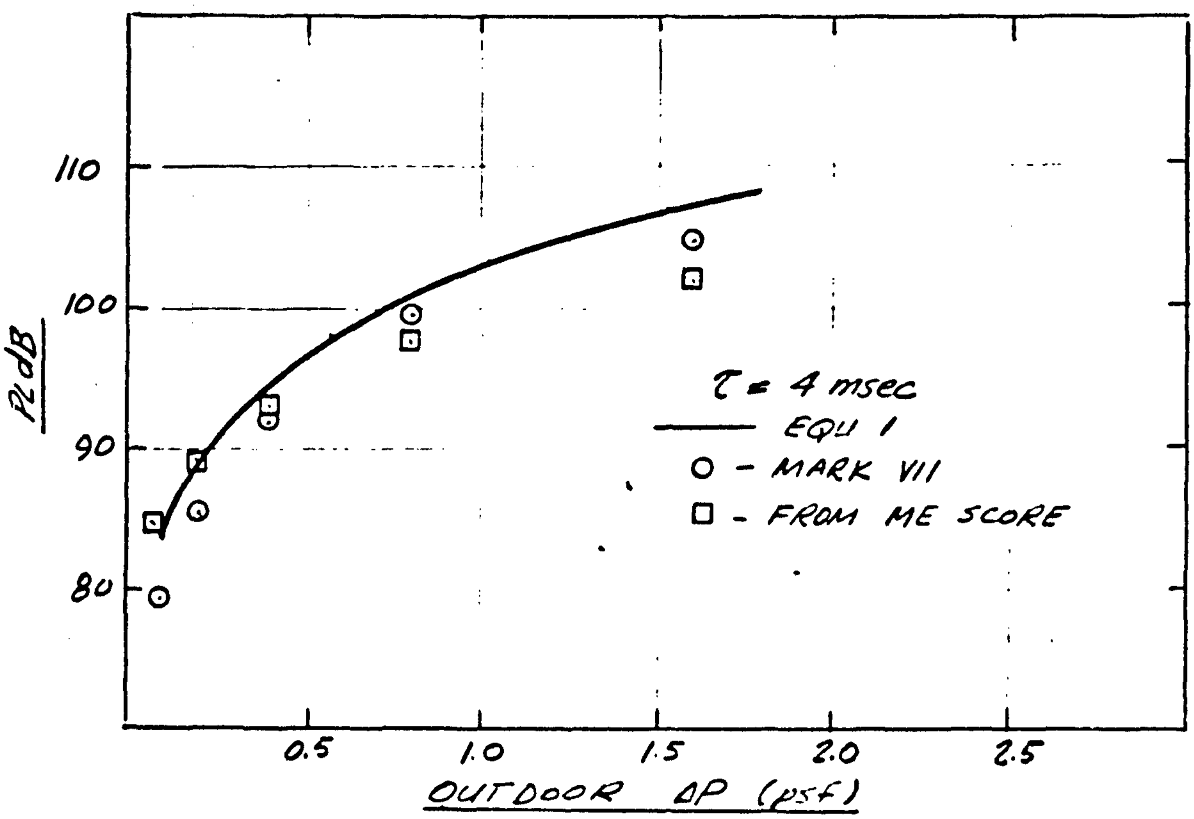


FIGURE 14A - SUMMARY OF OUTDOOR RESPONSE DATA FOUR AND FOUR AND SIX msec RISE TIMES

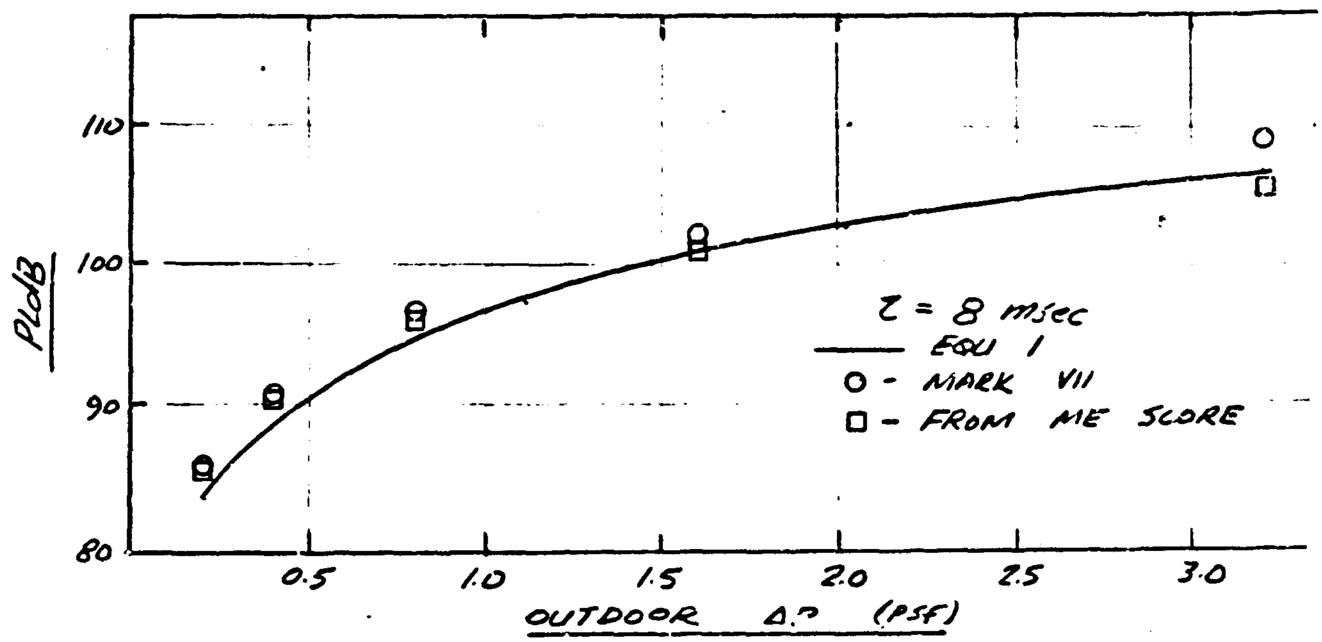


FIGURE 14B - SUMMARY OF OUTDOOR RESPONSE DATA
EIGHT msec RISE TIME

TABLE IV

COMPARISON OF PREDICTED PLdB WITH PLdB DERIVED

FROM OUTDOOR MAGNITUDE ESTIMATION SCORES

	Predicted PLdB		Magnitude Est. PLdB
Boom Type	PLDB(1)	(PLdB)VII*	PLdB(M.E.)**
1	83	78	85.5
2	83	85.7	86
3	83	-	90
4	89	85	89.5
5	89	84.6	90.7
6	89	91	91
STD → 7	95	91.5	92.5
8	95	91.5	95.5
9	95	97	96
10	101	99.5	97
11	101	97.5	100
12	101	102.5	102
13	107	104.5	101.5
14	107	103.5	104.6
15	107	109.5	104.8

*Based on measurement of the third active band spectrum of the test signal

**Using Equation (1) to fix magnitude estimation scale of 10 at 95 PLdB(1), and $PLdB(M.E.) = 75 + 20 \log_{10} R_o$

A similar analysis of the magnitude estimation results has been performed for the test signals as heard indoors.

Figure (15) presents the indoor magnitude estimation average scores for 21 subjects. The results are plotted against PLdB(1) as heard indoors. The behavior of the data appears quite similar to the outdoor magnitude estimation results, however, it is necessary now to recall that the boom as heard indoors has a reduced over-pressure, and a longer rise-time compared to the corresponding outdoor sonic boom.

Again using the magnitude estimation level of 10 as the standard, with the corresponding values of ΔP and τ, we can calibrate the ordinate of Figure (15) according to the relation

$$PLdB(M.E.) = 51.5 + 20 \log_{10} R_i$$

where R_I is the indoor magnitude estimation response. When this is done the M.E. level of 10 has a PLdB(M.E.) of 71.5 based on the indoor $\Delta P = 0.15$ psf and $\tau = 22$ msec, which correspond to the indoor standard level. As with the outdoor results the subjective scores presented as PLdB levels can be compared with the results of each of the prediction methods. This is done in TABLE V and in graphical form in Figure (16) which plots the PLdB level as heard indoors versus the outdoor over-pressure.

As in the case of the outdoor magnitude estimation scores, these results also show reasonable agreement between the prediction methods and the subjective response data. Based on this comparison we conclude that the engineering formula of Equation (1) is adequate for predicting indoor PLdB and that the subjective experiment using magnitude estimation provides a valid evaluation of the sonic boom as heard indoors.

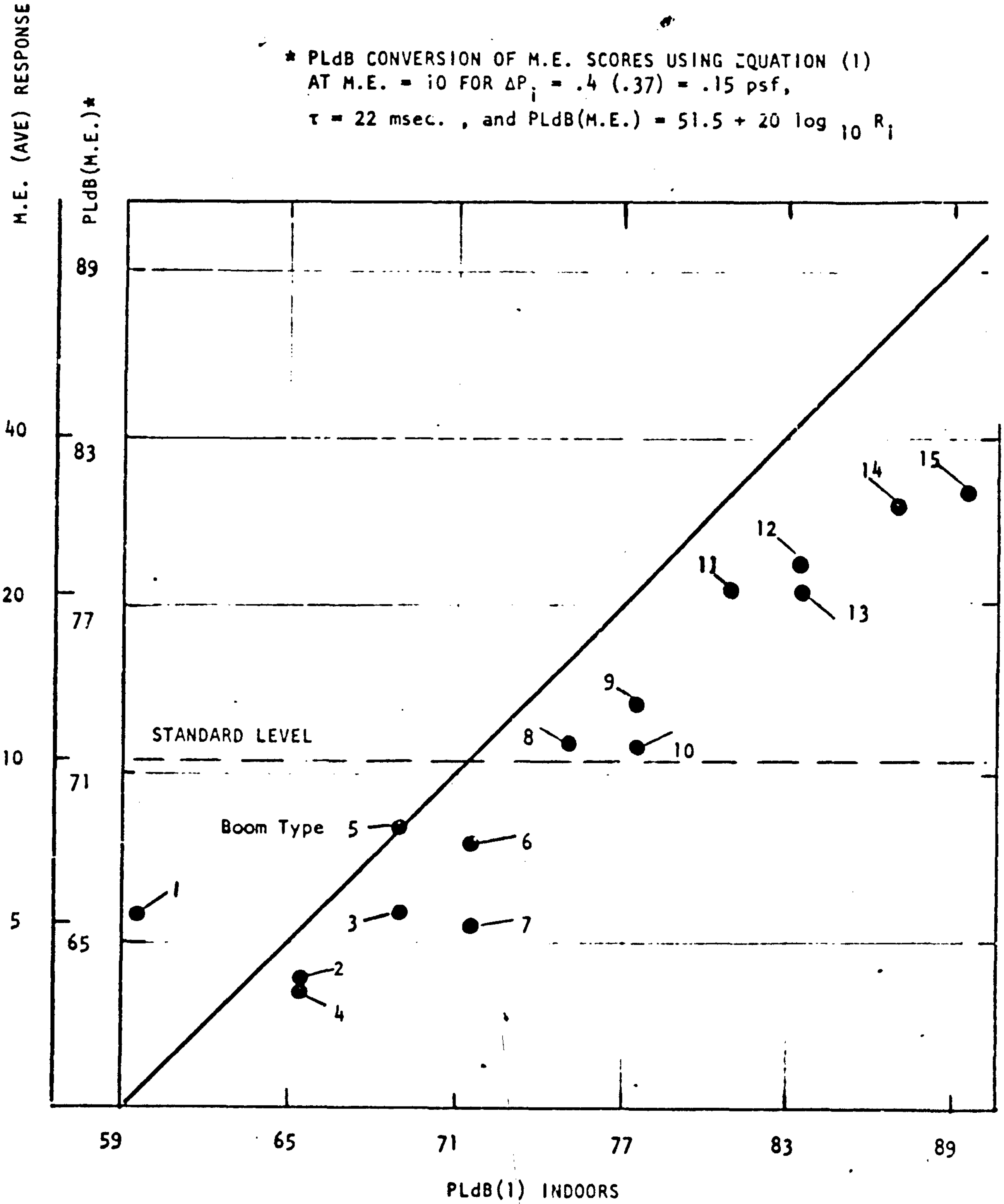


FIGURE 15 - AVERAGE M.E. SCORE - INDOOR RESULTS - 21 SUBJECTS

TABLE V

COMPARISON OF PREDICTED PLdB WITH PLdB DERIVED FROM INDOOR MAGNITUDE ESTIMATION SCORES

Boom Type	Predicted PLdB		Magnitude Est. PLdB
	PLdB(I)	PLdB(VII)*	PLdB(M.E.)**
1	59.5	53	66
2	65.5	57.8	63
3	69	-	66
4	65.5	58.8	63
5	69	65.5	69
6	71.5	64.6	68.5
7	71.5	65.6	66
8	75	70.8	72
9	77.5	70.8	73.5
10	77.5	71.6	72
11	81	76	77.7
12	83.5	76.3	78.5
13	83.5	78	77
14	87	81.5	80.5
15	89.5	82.5	81
	$\Delta P = .37(\Delta P)_{out}$ $\tau = 22$ ms.		

*Based on measurement of the third active band equation of the test signal.

**Using Equation (1) to fix magnitude estimation scale of 10 at 95 PLdB(I) and $PLdB(M.E.) = 51.5 + 20 \log_{10} R_I$.

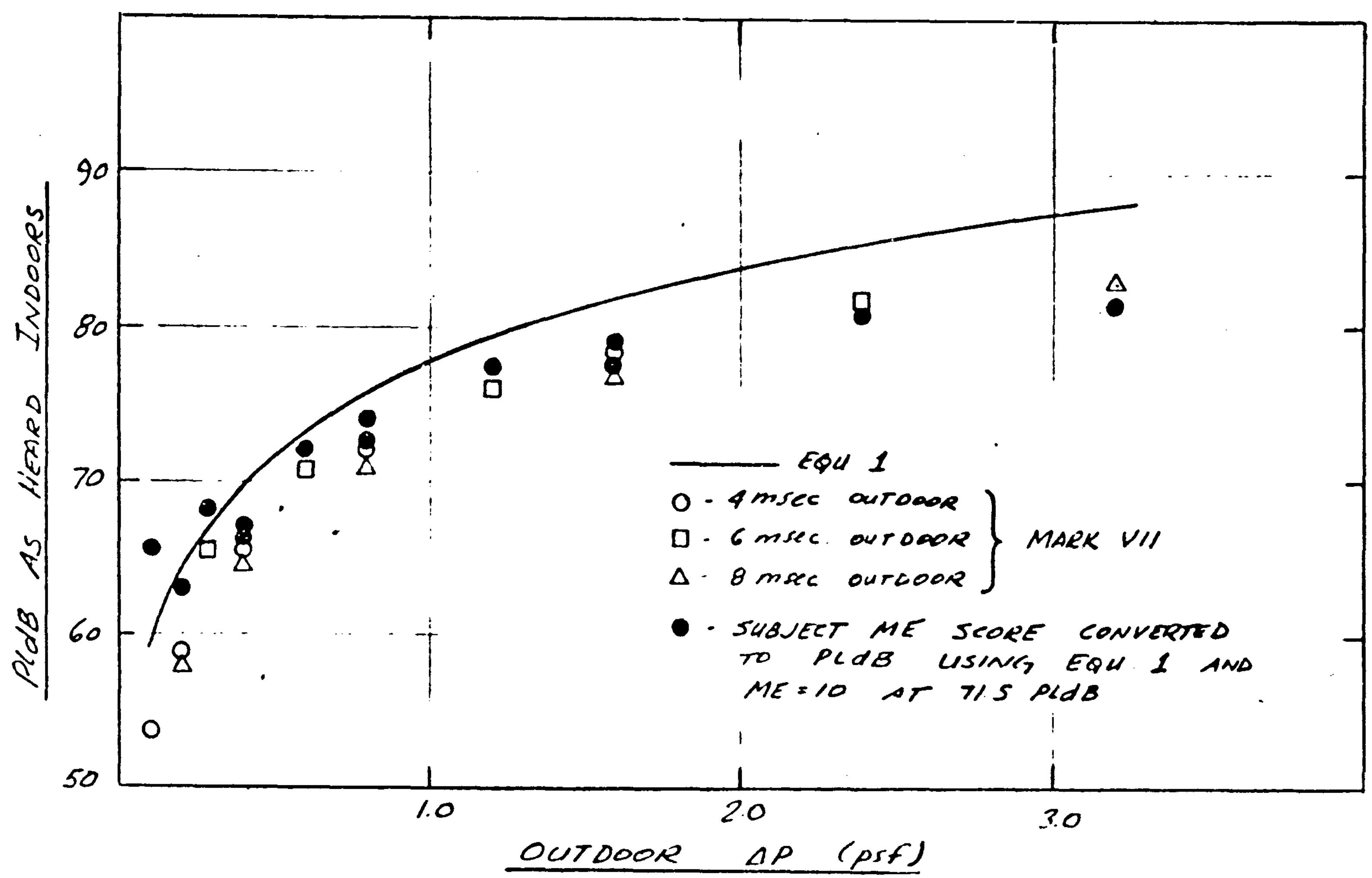


FIGURE 16 - SUMMARY OF INDOOR RESPONSE DATA

(b) Effects of Noise Sensitivity on Scores - As stated earlier, the subjects were screened for noise sensitivity and two groups were established; high level, scoring 5-10 on a scale of 10, and low, scoring 0-4. As with scores in general it is useful to look at how the two groups scored the standard boom which we know should have an annoyance score of 10.

In the outside condition, those with sensitivity 0-4 rated the boom at an average of 10.18, $\sigma = 3.4$. Those with sensitivity 5-10 rated the same boom at 12.77, $\sigma = 5.0$.

In the interior condition, the subjects rated 0-4 scored the standard boom at an average of 10.67, $\sigma = 3.14$. Those with sensitivity 5-10 scored it at 14.79, $\sigma = 7.41$.

Finally, the 0-4 sensitivity group overall rated the standard boom at an average of 10.04, $\sigma = 3.3$, while the 5-10 group overall rated the boom at 13.54, $\sigma = 6.43$. These differences are not statistically significant as determined by a t-test.

It appears then that noise sensitivity is a factor to some very limited extent in studying the sonic boom. The results observed in relation to the standard boom are also seen in the other boom types. However, it is not an overriding consideration.

(c) Acceptability - The subjects were asked to respond to each boom according to whether or not they felt they could live with it if they heard it

on a regular basis. Figure (17) shows the percentage of times a boom was rated as acceptable. (Each boom was heard twice, once in each test series, resulting in 84 responses per boom type.) Since 80% acceptability has frequently been cited as an optimal level to attain, it is indicated on the graph. Table VI shows the actual data.

The only boom to attain an overall (regardless of sensitivity or location) rating of above 95% was boom type 1, at 83 PLdB(1), 0.1 psf and 4 msec. rise time. The outdoor rating was just over 90% , while inside it was 100%. The next three boom types (2 at 83 PLdB(1) one at 89 PLdB(1)) attained an overall level of over 80% , and the following four boom types (reaching to 95 PLdB(1)) had an overall acceptability of over 50%. The standard boom itself, number 7, 95 PLdB(1) .4 psf and 4 msec rise time, had an overall acceptability of 73.8%. The higher level booms showed a rapidly decreasing acceptability.

Indoor acceptability remained above 80% through boom type 7 compared to an outdoor level of only boom type 4. The threshold was above 50% through boom type 10 indoors, and only through type 7 outdoors. Thus, despite creaks and small rattles, the indoor group felt the booms were tolerable to higher levels than the outdoor subjects. It may be inferred that the major component of the annoyance the people experienced was due to the effects of noise. Once again, below 50%, the acceptability in both locations dropped sharply.

The acceptability results are plotted in more detail in Figures (18) through (21). Outdoor acceptability determined from the low noise sensitivity subjects

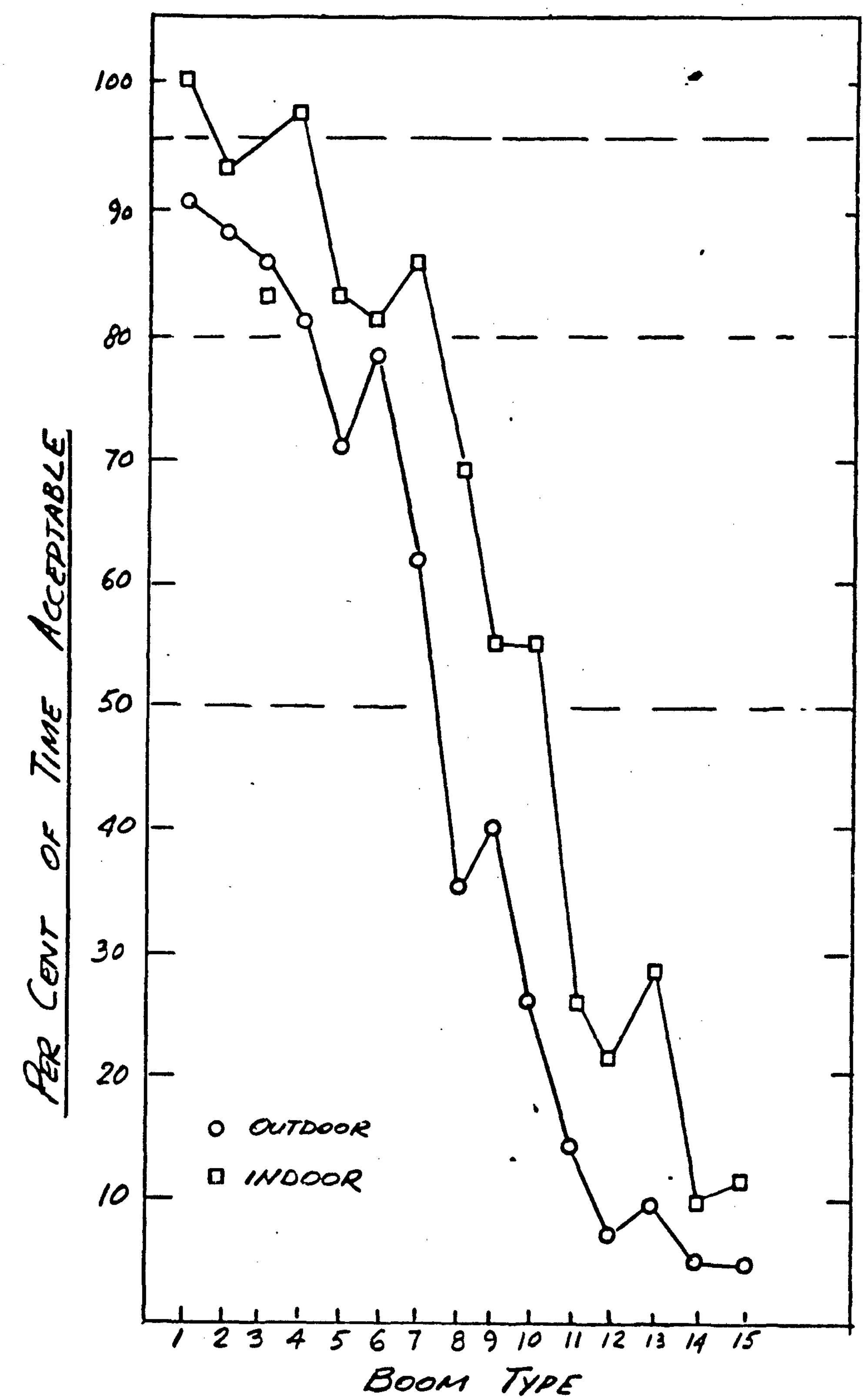


FIGURE 17 - ACCEPTABILITY

TABLE VI

NUMBER OF TIMES BOOMS RATED ACCEPTABLE

(Each Boom Rated Twice By Each Subject)

Boom Type	0-4 Outdoor	0-4 Indoor	5-10 Outdoor	5-10 Indoor	0-10 Outdoor	0-10 Indoor	Overall	% Overall
1	18 of 20	16 of 16	20 of 22	26 of 26	38 of 42	42 of 42	80 of 84	95.2
2	18	16	19	23	37	39	76	90.5
3	16	16	20	19	36	35	71	84.5
4	16	16	18	25	34	41	75	89.3
5	15	16	15	19	30	35	65	77.4
6	16	15	17	19	33	34	67	79.8
7	12	14	14	22	26	36	62	73.8
8	7	14	8	15	15	29	44	52.4
9	7	12	10	11	17	23	40	47.6
10	4	12	7	11	11	23	34	40.5
11	3	6	3	5	6	11	17	20.2
12	1	4	2	5	3	9	12	14.3
13	1	5	3	7	4	12	16	19.0
14	-	2	2	2	2	4	6	7.1
15	-	2	2	3	2	5	7	8.3
	max=20	max=16	max=22	max=26	max=42	max=42	max=84	

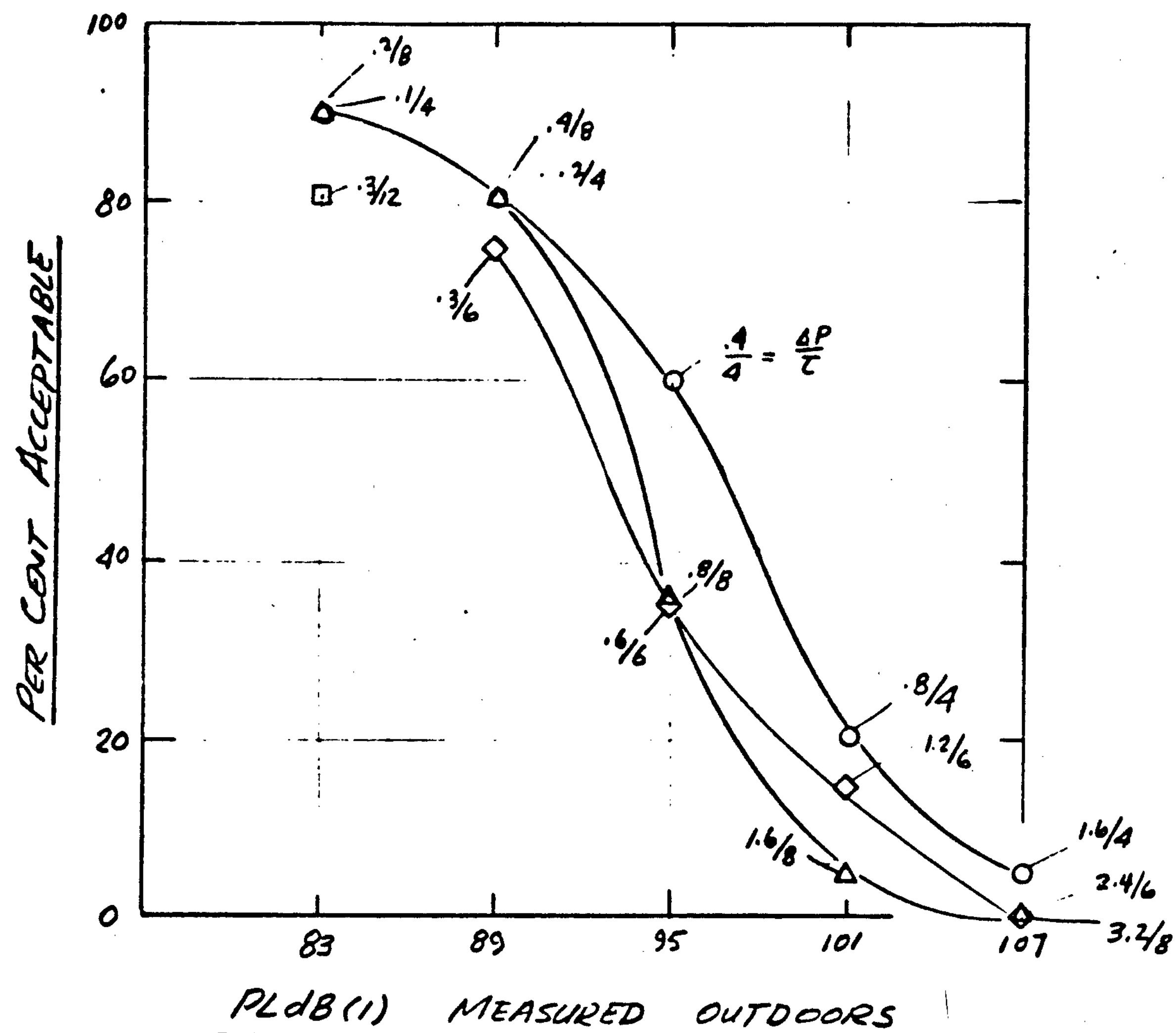


FIGURE 18 - OUTDOOR ACCEPTABILITY OF SONIC BOOMS
SUBJECTS WITH LOW NOISE SENSITIVITY

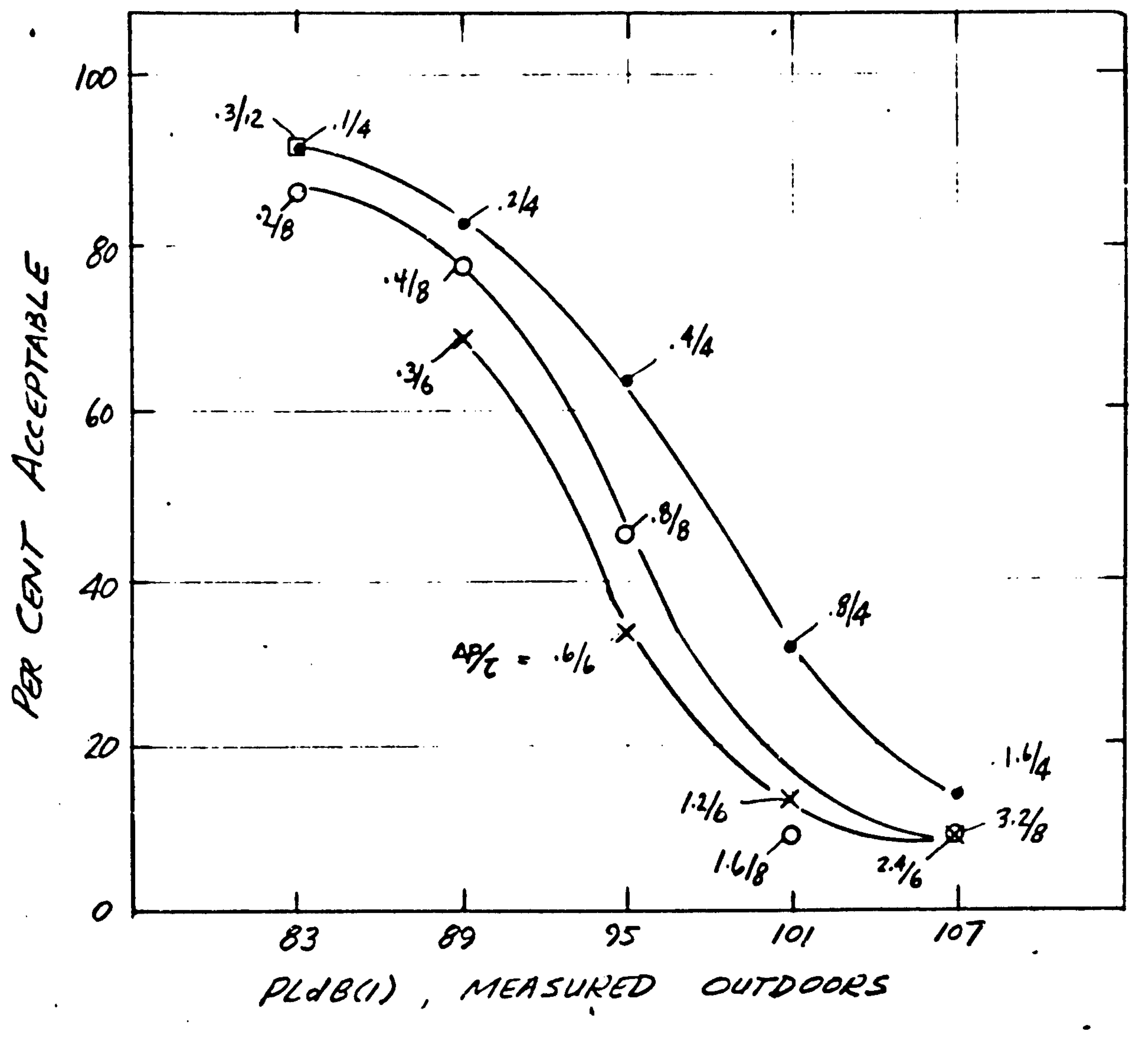


FIGURE 19 - OUTDOOR ACCEPTABILITY OF SONIC BOOMS - SUBJECTS WITH HIGH NOISE SENSITIVITY

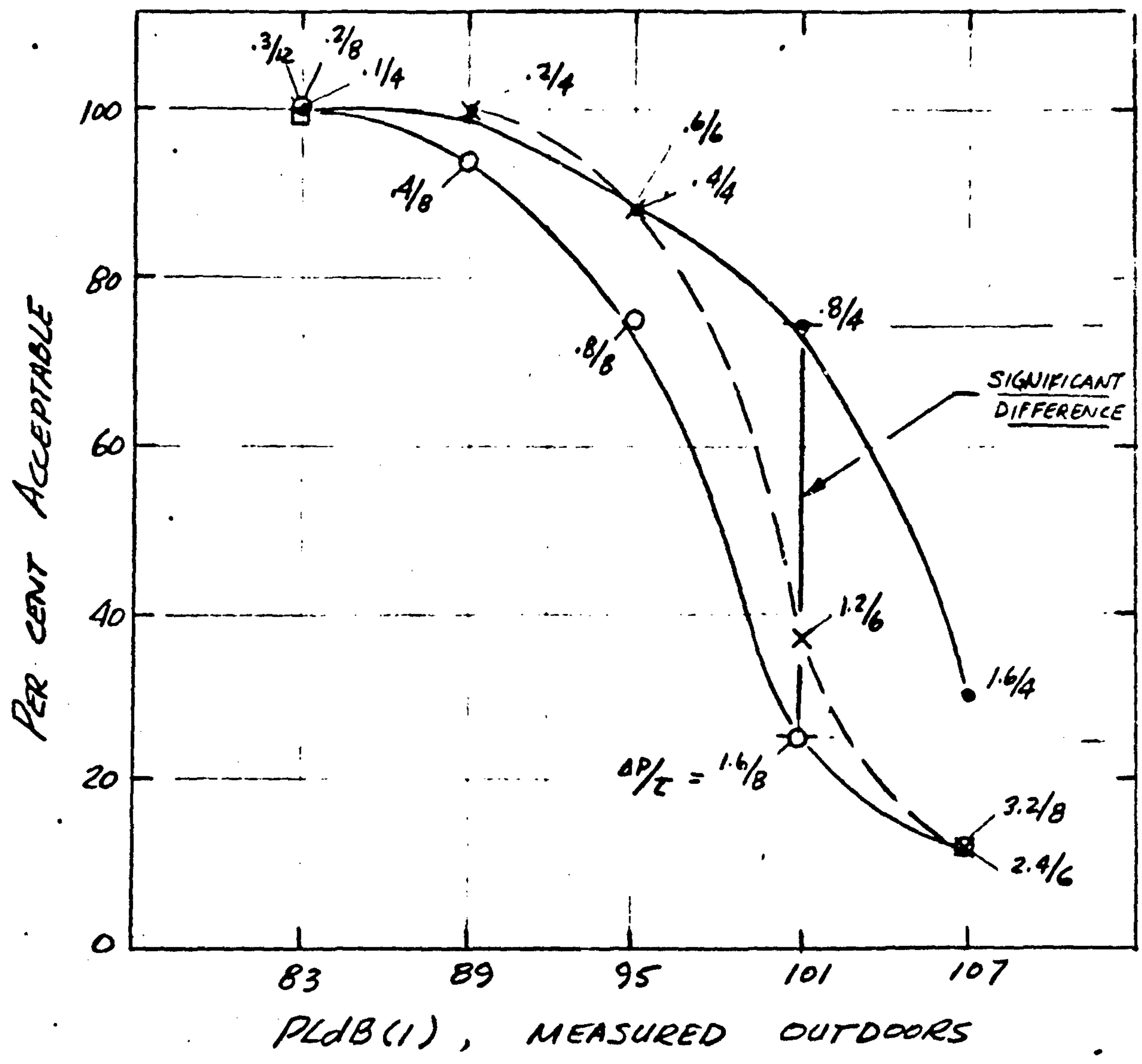


FIGURE 20 - INDOOR ACCEPTABILITY OF SONIC BOOMS
SUBJECTS WITH LOW NOISE SENSITIVITY

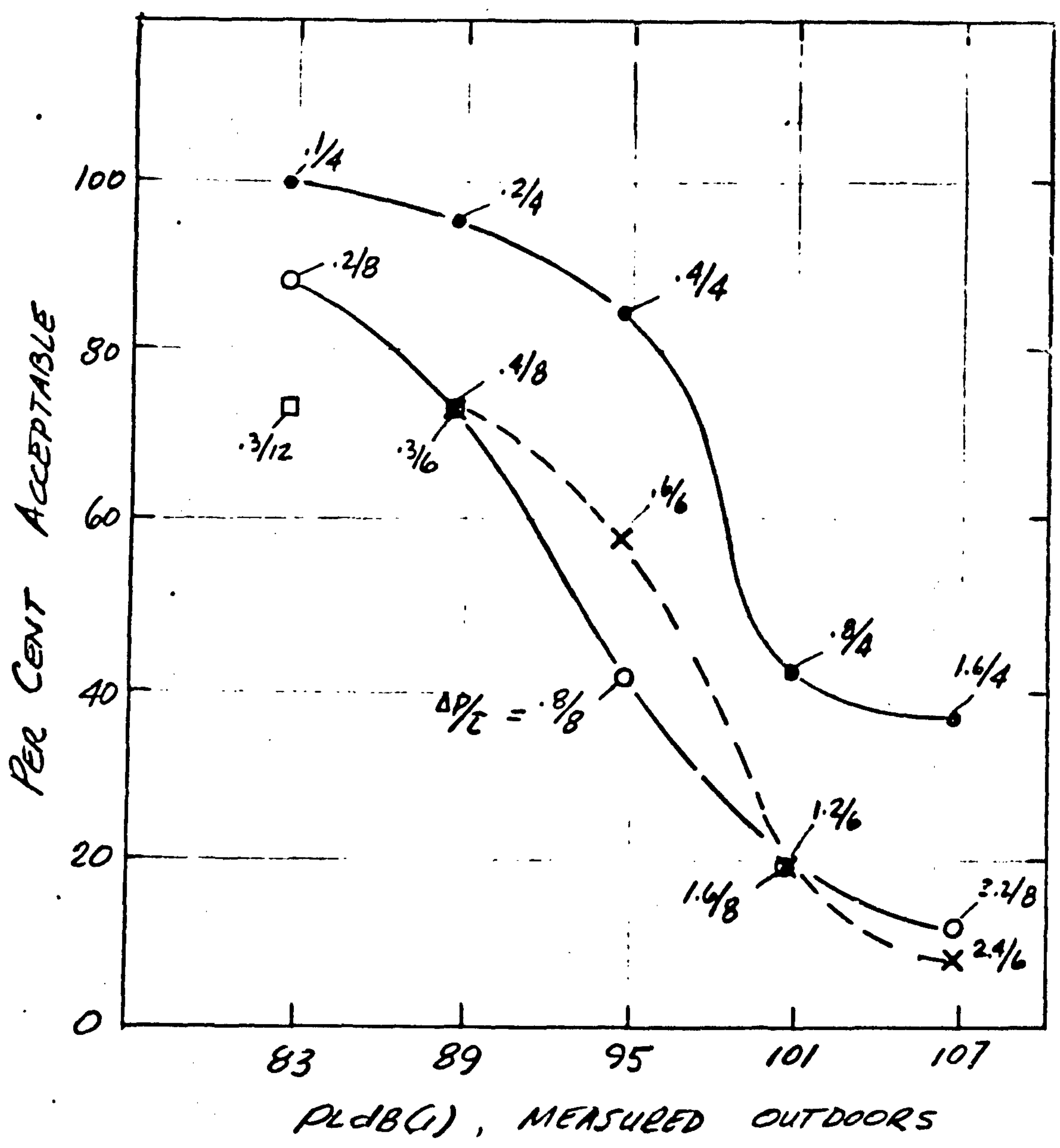


FIGURE 21 - INDOOR ACCEPTABILITY OF SONIC BOOMS
SUBJECTS WITH HIGH NOISE SENSITIVITY

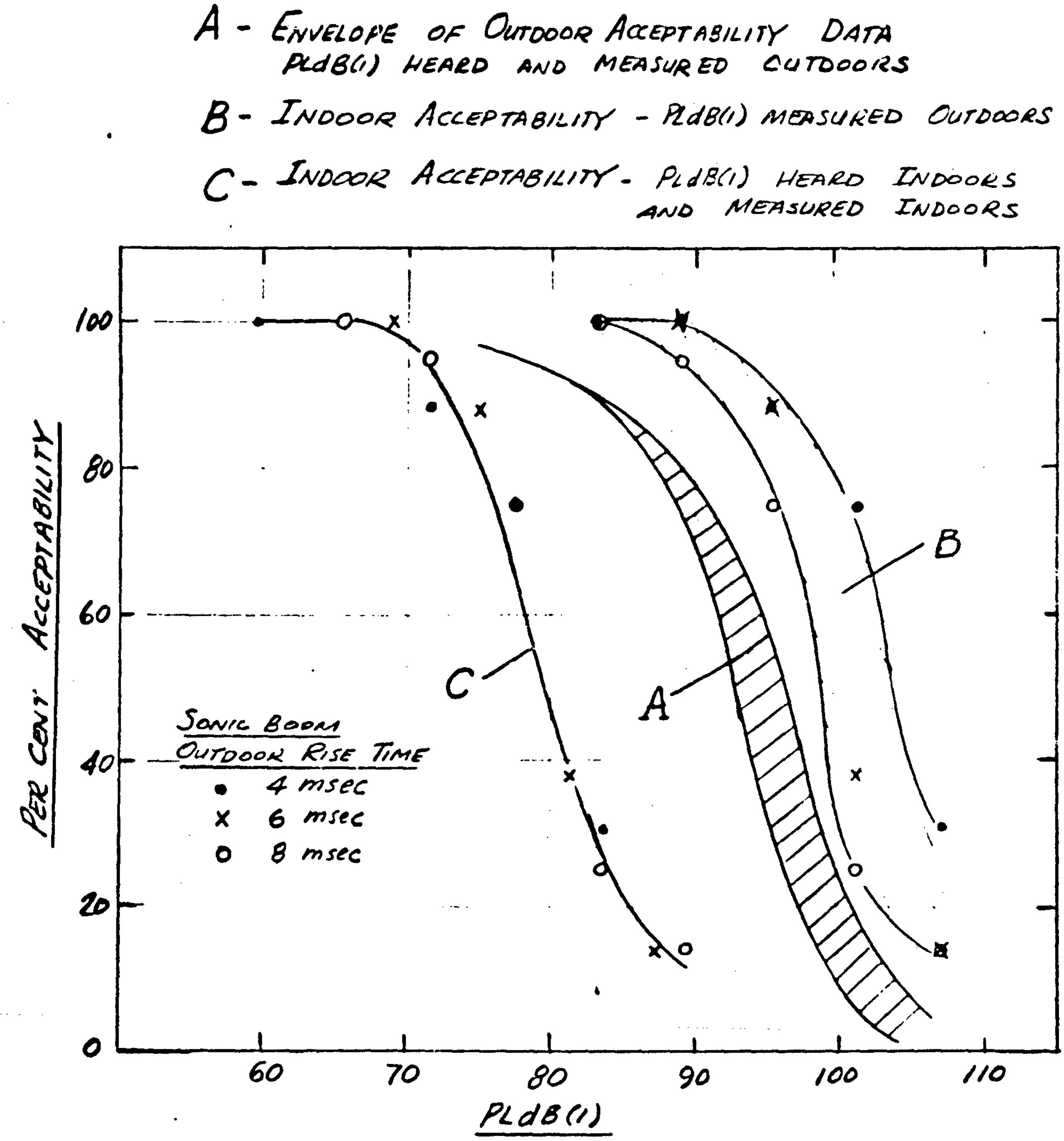


FIGURE 22 - COMPARISON OF INDOOR AND OUTDOOR ACCEPTABILITY
SUBJECTS WITH LOW NOISE SENSITIVITY

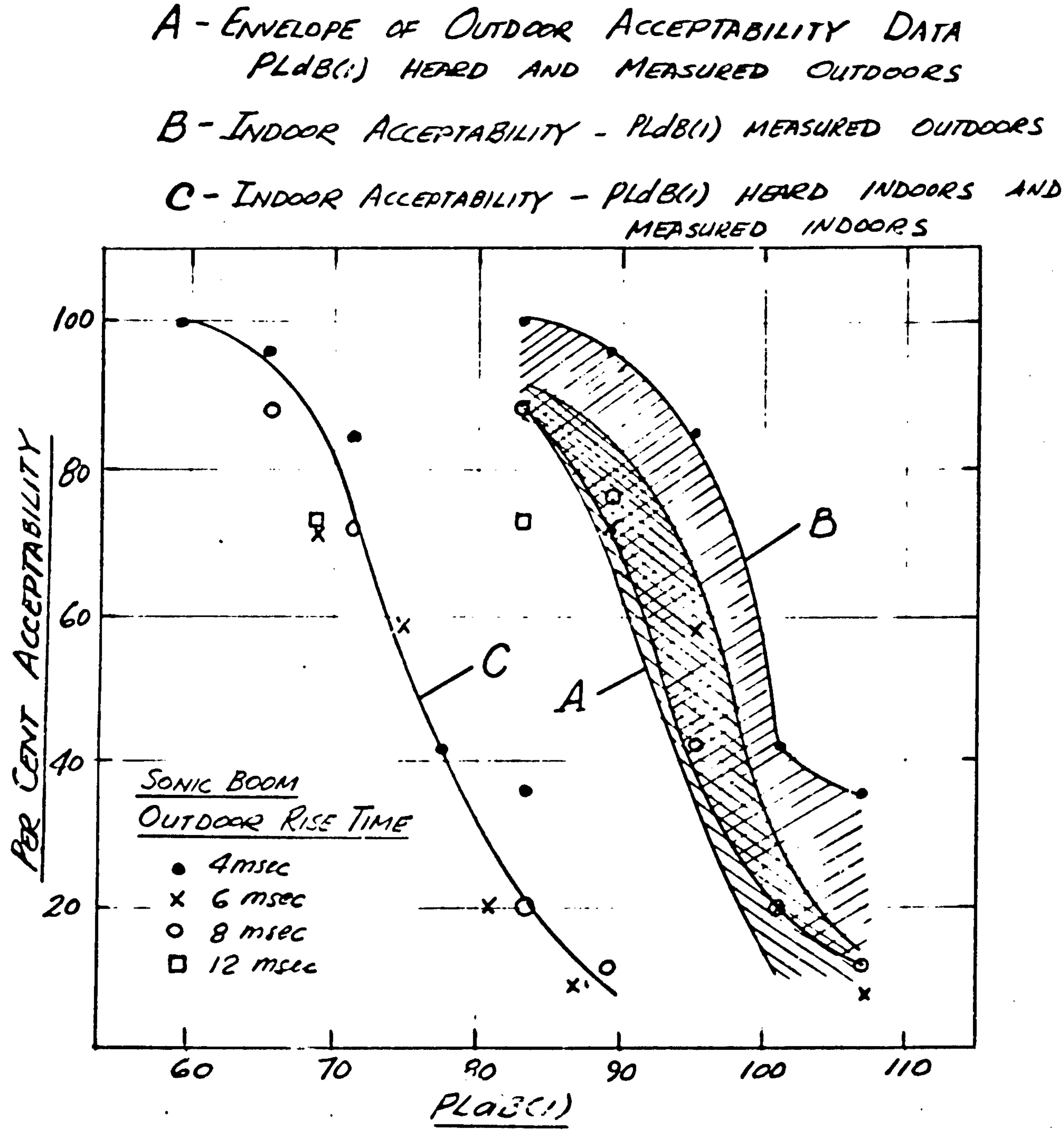


FIGURE 23 - COMPARISON OF INDOOR AND OUTDOOR ACCEPTABILITY
SUBJECTS WITH HIGH NOISE SENSITIVITY

is shown in Figure (18). The curves through the data points correspond to constant values of rise time. Each point is labeled to show the outdoor over-pressure (as a numerator) and the rise time in msec (as a denominator). A statistical analysis of the variance between the levels of acceptability for each value of PLdB (1) shows there is no significant difference in the reported level of acceptability.

With regard to the more noise sensitive subjects, the results of acceptability for subjects tested outdoors are shown in Figure (19). As in the case of the low sensitivity subjects, there is no significant difference between the ratings for outdoor acceptability at all levels of PLdB (1).

This result suggests that Equation (1) is useful for predicting outdoor acceptability of sonic boom using the parameter $\Delta P/\tau$. With regard to indoor acceptability, for both the low and high noise sensitivity group of subjects, we find an apparent difference in the acceptability at 101 PLdB(1) level for the low noise sensitive group (Figure 20), and at 95 and 101 PLdB(1) level for the high noise sensitive group (Figure 21), however, these differences may not be real since the PLdB(1) actually heard indoors is not proportional to PLdB(1) heard outdoors because of the manner in which indoor over-pressure and rise-time are altered by transmission through the wall. To evaluate the indoor acceptability data, we must compare the ratings in terms of the PLdB(1) actually heard indoors. This has been done in Figure (22) for the low noise sensitivity subjects and in Figure (23) for the high noise sensitivity subjects. Each of these figures show the band of acceptability data corresponding to the outdoor subjects plotted vs the PLdB(1) measured outdoors, the acceptability data of indoor subjects vs PLdB(1) measured outdoors; and finally, the same acceptability data of the indoor subject plotted vs the PLdB(1) measured indoors. For both the low and high sensitive groups we observe a shift of the indoor acceptability curve to

lower values of PLdB, as expected. More significantly, however, is the fact that the acceptability data for all the indoor acceptability ratings collapse to a single curve. This correlation of the indoor acceptability data implies a constant value of indoor rise time, which was in fact, found to be the case for the boom as heard indoors, and implies that Equation (1) applied to the over-pressure and rise time as measured indoors is suitable for the evaluation of sonic booms as heard indoors.

(d) Effect of Noise Sensitivity on Acceptability - The subjects with lower sensitivity to noise tended to rate as acceptable booms of higher levels than those more sensitive to noise. The total 0-4 group rated booms through type 6 at over 80% and through type 9 at over 50% acceptable. The total 5-10 group only rated as acceptable over 80% of the time those booms through type 4 and above 50% through type 7. As with annoyance M.E. scores, noise sensitivity does play a role, albeit a small one. Figure (24) shows the relationship between acceptability and sensitivity for the total subject population.

Figure (25) shows the same comparison for the indoor subjects only in terms of the PLdB(1) level heard and measured indoors.

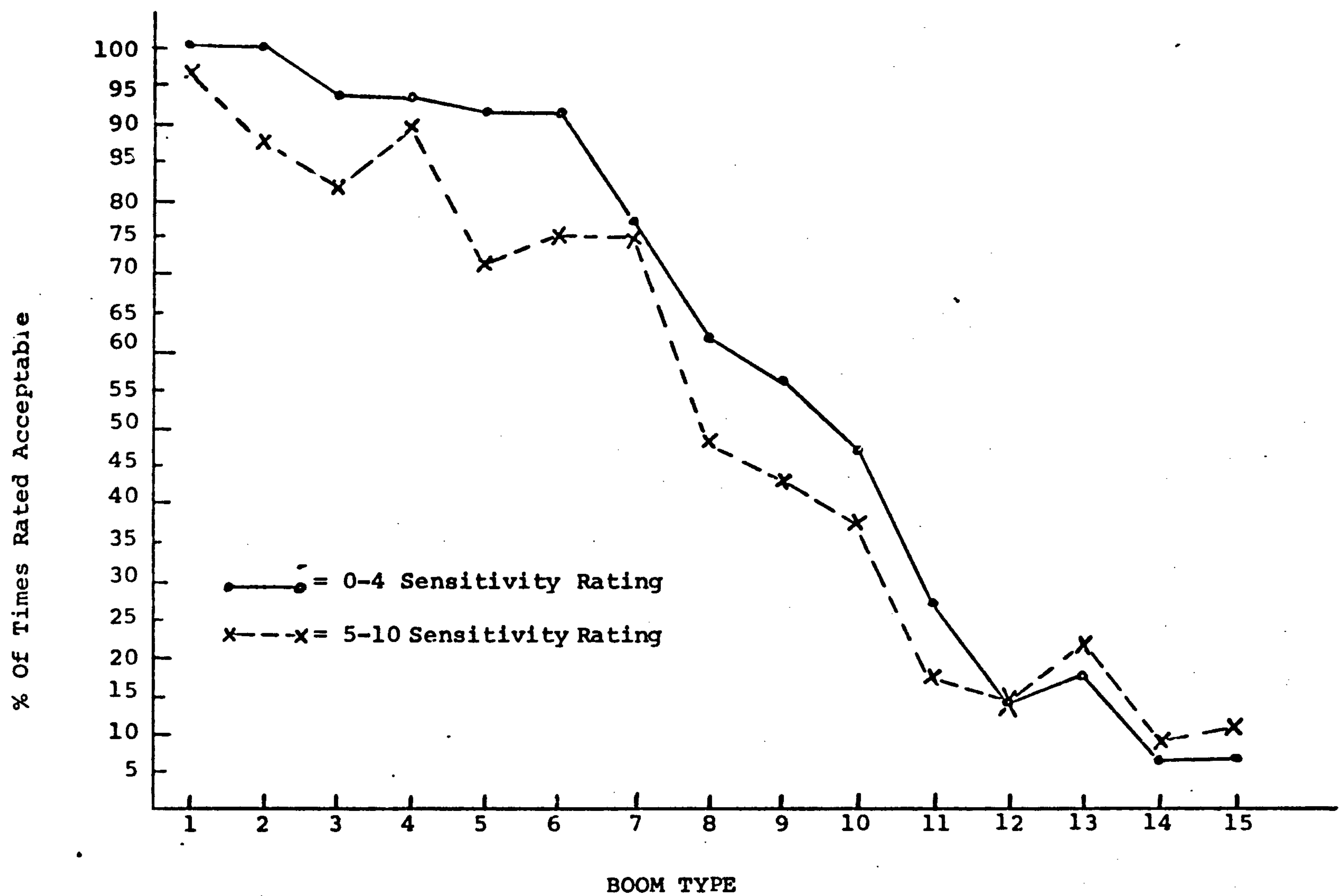


FIGURE 24 - RELATIONSHIP BETWEEN ACCEPTABILITY AND NOISE SENSITIVITY
COMBINED DATA INDOOR AND OUTDOOR

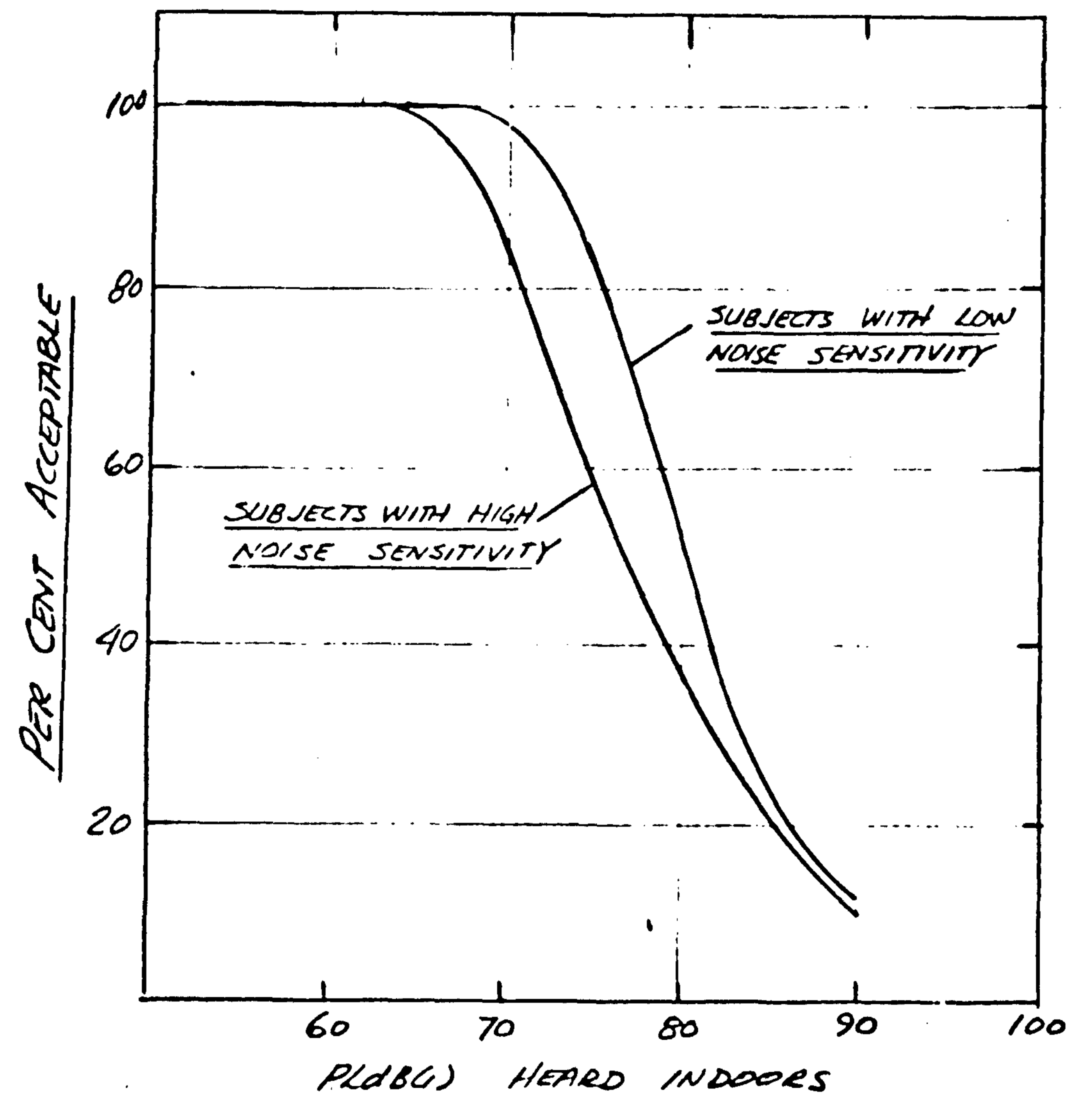


FIGURE 25 - AVERAGE INDOOR ACCEPTABILITY ACCORDING TO SUBJECTS' NOISE SENSITIVITY

SECTION IV

DISCUSSION

The data shown in Figures (22) and (23) are the important experimental results derived from this program and bear further discussion. Comparing the acceptability results from the high and low sensitivity groups for the outdoor sonic boom, it is seen that there is no significant difference between the two acceptability curves.

Acceptability results, for the low noise sensitive subjects, when plotted against the boom as measured outdoors, shows a higher level of acceptability at every FLdB (1) level, as might be expected. For the noise sensitive subjects, however, the indoor subjects responded with a reduced acceptability compared with that of the less noise sensitive subjects, and it can be seen that the indoor results are nearly coincident with those of the outdoor acceptability data.

It was pointed out earlier, however, that the indoor acceptability data should properly be plotted against the PLdB (1) level determined from the over-pressure and rise time actually heard indoors. This presentation was, therefore, shown in both Figures (22) and (23).

We would expect that the difference between the indoor acceptability data when compared against the value of PLdB (1) determined from the outdoor and indoor measured levels of over-pressure and rise time would be the attenuation through the wall. The observed difference for both sets of data

(Figures 22 and 23) is seen to be a constant value of approximately 20 dB over the complete range of PLdB level. This agrees quite well with the db attenuation through a frame wall structure. For example, Harris (Refe·ence 13), shows an average sound transmission loss of 25 dB for a frame wall. What is more interesting in this result is the significantly lower acceptability recorded by the indoor subjects compared with that of the outdoor subjects when compared on the basis of PLdB(1) determined from the respective indoor and outdoor over-pressures and rise times. Intuitively, one would have expected that subjective acceptability would have been the same whether indoor or outdoor given as in this experiment, that identical subject instructions were employed for each group, and that group developed acceptability ratings based on standard levels heard in his own independent environment.

We conclude from this result that other subjective factors must have entered to affect the acceptability ratings of the indoor subjects in an adverse manner so as to yield a lower acceptability curve. One can perhaps speculate that the difference noted is the "intrusive penalty" paid when subjecting a person to noise in his own home.

With regard to the subject's attitude toward SST influencing the present results, an attempt was made to evaluate this factor. All subjects were asked questions to determine their biases in relation to SST. The questions concerned the degree of necessity for the aircraft, and its desirability as well.

Of the 42 subjects, 28 (66.7%) felt the SST is necessary to some degree. The reason given included: for trade, for national prestige, for technological progress, for rapid travel.

However, of these 28, 13 felt that such a fast airplane was not desirable. That is to say, 46.4% of those who feel the plane is a necessity also feel it is not desirable, either because of environmental effects, slow ground transportation negating its speed, or just the feeling that everything is going too fast already.

Of the 42 subjects, 14 (33.3%) felt there is no necessity at all for a supersonic commercial aircraft. Only 2 of those 14 felt the SST is desirable, despite its lack of necessity. Table VII shows the different attitudes.

Although it has been shown in the past that attitudes can be important in affecting judge[illegible] there is little evidence of that in our results. We saw before that those with low noise sensitivity rated more booms as acceptable over 50% and 80% of the time than the high sensitivity group. Now we see that those with low noise sensitivity are also more inclined to see the SST as a necessity than the highly-sensitive people. The group with 0-4 sensitivity ratings felt the SST is a necessity (to some degree) in 72.2% of the cases, whereas the group rated as 5-10 felt the SST is a necessity in 62.5% of the cases.

TABLE VII

SST ATTITUDES

Noise Sensitivity	0-4	0-4	0-4	5-10	5-10	5-10	0-10	0-10	
Location	Outdoor	Indoor	Overall	Outdoor	Indoor	Overall	Outdoor	Indoor	Overall
Absolutely or Probably Necessary (desirable or not)	8	5	13	6	9	15	14	14	28
Probably Necessary and Desirable	2	1	3	0	3	3	2	4	6
Probably Necessary, But Not Desirable	3	3	6	3	4	7	6	7	13
Absolutely Necessary, (also desirable)	3	1	4	3	2	5	6	3	9
Not Necessary, But Desirable	0	1	1	1	0	1	1	1	2
Not Necessary and Not Desirable	2	2	4	4	4	8	6	6	12

With respect to the acceptability results, it is pertinent to comment on one additional aspect of this measurement program. It will be observed that the psychoacoustic experiment design, and in particular the instructions to the subject for rating the magnitude of the boom, explicitly asked that the annoyance level of the boom be judged as opposed to judging a loudness level. In all probability the approach taken with regard to emphasizing annoyance level instead of loudness level leads to a more conservative judgment of the tolerability of the sonic boom, however, it is interesting to speculate on how the results might have been influenced had the subjects been asked to judge loudness instead of annoyance.

SECTION V

SUMMARY AND CONCLUSIONS

A subjective valuation of simulated sonic booms heard indoors and outdoors has been carried out to assess the validity of a simple formulation for estimating perceived noise levels. Using a psychoacoustic experiment design based on magnitude estimation of the perceived level, it was shown that the subjective response was consistent with the predictions of both the simple formula for PLdB as well as PLdB determined from an analysis of the sonic boom stimuli using the MARK VII procedure. Based on these results it is concluded that perceived sonic boom levels can be adequally predicted by the expression:

$$\text{PLdB} = 55 + 20 \log_{10} \frac{\Delta P}{\tau}, \quad \Delta P \text{ in psf}, \; \tau \text{ in secs.}$$

With regard to acceptability of the sonic boom, it was found that the sonic boom when heard indoors was significantly less acceptable than when heard outdoors for the same level of PLdB. In particular the present data indicate:

(a) 90 PLdB(1) when heard inside and measured outside is acceptable to 98% of the subjects tested; a result that is in agreement with the data reported in Reference (12).

(b) When heard inside and measured inside, the PLdB(1) and 98% acceptability is equivalent to 69 PLdB(1) (-21 PLdB attenuation).

(c) Heard outside and measured outside 90 PLdB(1) is acceptable to 80% of the tested subjects.

The present conclusions were derived from a test program which examined a limited range of parameters which can comprise the operating envelop of supersonic aircraft. Further work should examine these conclusions in relation to higher over-pressure and large rise times. In addition, future research should evaluate the physchological merit of modified sonic boom bow shock shapes.

SECTION VI

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APPENDIX A

COMPARATIVE ANALYSIS OF THE TEST SIGNALS

This appendix presents the results of an analysis of the third-octave band spectra of the indoor and outdoor test stimuli. The calculations were provided through the courtesy of Dr. James E. Mabry of Man-Acoustics, Inc.

TABLE A1 presents the outdoor levels of dBA, dBD, dBE, PNL using Kryters method, PL using Stevens MARK VI, and PL using Stevens MARK VII for fourteen Spectra corresponding to the outdoor boom as computed by Man-Acoustics, Inc. These results can be compared with the PLdB level according to Equation (1), the MARK VII calculation as determined during the present program. The last column of TABLE A1 presents the mean log magnitude estimates corresponding to each boom, averaged by the number of times the boom was scored.

TABLE A2 is a similar tabulation corresponding to the test signal as heard indoors.

Working with the matrix of data given by TABLES A1 and A2, the degree of correlation between each method of assessing the sound levels was determined. These results are shown in the correlation matrix provided by TABLE A3. It can be seen that all the calculation procedures work well, including PLdB from Equation (1) and the assessment derived from the magnitude estimation technique.

It is of interest to compare the number of dB for doubling or halving perceived level for each of the calculated procedures and the magnitude estimation method.

These results are presented in TABLE A4 for both the indoor and outdoor test signals. An average rate of change of 8 dB for outdoor exposure and 7 dB for indoor exposure is indicated.

TABLE A1

OUTDOORS

	MAN-ACOUSTICS, INC.						GASL		
	DBA	DBD	DBE	PNL	PL6	PL7	PLdB(I)	PL7	ME
1	75.1	82.1	73.7	88.2	87.4	80.4	83.0	78.0	.488
2	82.2	88.0	85.8	94.6	92.4	95.2	83.0	85.7	.514
3							83.0		
4	80.9	88.0	85.5	94.3	92.4	84.9	89.0	85.0	.662
5	81.6	87.2	85.0	94.5	92.2	84.6	89.0	84.6	.777
6	88.2	94.0	91.8	100.7	97.9	91.3	89.0	91.0	.749
7	86.8	93.9	91.4	100.4	97.8	90.9	95.0	91.5	.844
8	87.7	93.2	91.0	100.6	97.7	90.6	95.0	91.5	.987
9	94.2	100.1	97.9	106.7	103.8	97.6	95.0	97.0	1.010
10	92.6	99.8	97.3	106.3	103.6	97.1	101.0	99.5	1.082
11	93.4	99.1	96.8	106.5	103.3	96.6	101.0	97.5	1.252
12	100.2	106.1	103.9	112.7	109.9	104.1	101.0	102.5	1.330
13	98.6	105.8	103.5	112.4	109.9	103.7	107.0	104.5	1.296
14	99.4	105.2	102.9	112.5	109.4	103.2	107.0	103.5	1.453
15	106.2	112.8	109.9	118.6	116.5	110.9	107.0	109.5	1.487

TABLE A1 (Cont'd)

INDOORS

	MAN-ACOUSTICS, INC.						GASL		
	DBA	DBD	DBE	PNL	PL6	PL7	PLdB(1)	PL7	ME
1	48.8	59.3	55.2	59.7	63.5	55.4	59.5	53.0	.302
2	54.7	62.7	59.9	65.8	68.8	60.3	65.5	57.8	.514
3							69.0		
4	54.7	65.3	61.1	65.9	69.0	61.0	65.5	58.8	.467
5	61.0	67.1	65.1	71.9	73.9	66.0	69.0	65.5	.698
6	60.7	68.7	65.9	72.1	73.9	65.5	71.5	64.6	.755
7	60.7	71.2	67.1	72.2	74.1	66.5	71.5	65.6	.697
8	67.0	73.1	71.1	78.2	79.2	71.3	75.0	70.8	.954
9	66.7	74.7	71.9	78.4	79.0	71.0	77.5	70.8	1.034
10	66.7	77.3	73.2	78.7	79.4	72.1	77.5	71.6	1.009
11	72.9	78.5	76.7	84.2	83.8	76.2	81.0	76.0	1.252
12	72.7	80.7	77.9	84.8	84.1	76.6	83.5	76.3	1.308
13	72.8	83.3	79.2	85.2	84.8	78.3	83.5	78.0	1.212
14	78.9	84.5	82.7	90.4	88.9	81.6	87.0	81.5	1.410
15	78.7	86.7	83.9	91.0	89.3	82.6	89.5	82.5	1.424

TABLE A2

GASL CORRELATION MATRIX OUTDOOR
INDOOR

	DBD	DBE	PNL	PL6	PL7(M)	PLdB(I)	PL7(G)	ME
DBA	.997 .979	.998 .994	.998 .999	.997 .999	.996 .997	.917 .991	.990 .997	.950 .993
DBD		1.000 .995	.999 .985	.999 .984	.999 .989	.930 .992	.995 .987	.947 .975
DBE			.999 .997	.999 .997	.999 .999	.927 .997	.994 .997	.946 .990
PNL				.998 1.000	.997 .999	.936 .995	.996 .998	.957 .994
PL6					1.000 .999	.933 .993	.993 .998	.952 .992
PL7 MAN						.927 .994	.991 .999	.948 .989
PLdB(I)							.947 .991	.972 .991
PL7 GASL								.950 .989

TABLE A3

NUMBER OF dB FOR DOUBLING OR HALVING PERCEIVED LEVEL

	OUTDOOR	INDOOR
DBA	8.36	7.52
DBD	8.36	7.17
DBE	8.36	7.34
PNL	8.36	7.92
PL6	7.92	6.54
PL7 (MAN)	8.60	6.84
PLdB(1)	7.72	7.34
PL7 (GASL)	8.60	7.52

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